INSTITUTION

414..

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1861.

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1861.

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1861.

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WITH YEAR OF ELECTION.

LIFE MEMBERS.

1852. **Brogden,** **Henry,** Sale, near Manchester.
1858. **Fletcher,** Henry Allason, Lowca Engine Works, Whitehaven.
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1854. **Lloyd,** George Braithwaite, Messrs. Lloyds, High Street, Birmingham.
1853. **Maudslay,** Henry, Club Chambers, 15 Regent Street, London, S.W.
1848. **Penn,** John, The Cedars, Lee, Kent, S.E.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Midland Works, Birmingham.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Locomotive Superintendent, Scottish Central Railway, Perth.
1856. Allen, Edward Ellis, 5 Parliament Street, Westminster, S.W.
1856. Allen, James, Cambridge Street Works, Manchester.
1859. Alton, George, Midland Railway Works, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
1856. Anderson, John, Assistant Superintendent, Royal Gun Factories, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Messrs. Courtney Stephens and Co., Blackall Place Iron Works, Dublin.
1858. Appleby, Charles Edward, Mining Engineer, 39 Mornington Road, Regent's Park, London, N.W.
1861. Armitage, Harry W., Farnley Iron Works, Leeds.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1857. Armstrong, Joseph, Great Western Railway, Locomotive Department, Wolverhampton.

1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1848. Bagnall, William, Gold's Hill Iron Works, Westbromwich.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1848. Baker, William, London and North Western Railway, Euston Station, London, N.W.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1847. Barwell, William Harrison, Eagle Foundry, Northampton.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Bordesley Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, Parkgate Iron Works, Rotherham.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1860. Beck, Richard, Lister Works, Upper Holloway, London, N.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1854. Bennett, Peter Duckworth, Spon Lane Iron Works, Westbromwich.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton, near Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Russell's Hall Iron Works, near Dudley.
1858. Bouch, William, Shildon Engine Works, Darlington.
1847. Bovill, George Hinton, Durnsford Lodge, Wandsworth, Surrey, S.W.
1858. Bower, John Wilkes, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1854. Bragge, William, Atlas Street Works, Sheffield.
1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.
1856. Bray, Edwin, Nevill Holt, near Market Harborough.
1861. Brierly, Henry, 19 Grosvenor Square, Lower Broughton, Manchester.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel Works, Sheffield.

1855. **Brown, John,** Mining Engineer, Barnsley.
1856. **Brown, John,** Mining Engineer, Bank Top, Darlington.
1853. **Brown, Ralph,** Patent Shaft Works, Wednesbury.
1858. **Burn, Henry,** Locomotive Superintendent, Danube and Black Sea Railway, Kustendjie, near Varna.
1856. **Butler,** Ambrose Edmund, Kirkstall Forge, Leeds.
1859. **Butler, John,** Old Foundry, Stanningley, near Leeds.
1859. **Butler, John Octavius,** Kirkstall Forge, Leeds.

1857. **Cabry, Joseph,** Midland Great Western Railway, Dublin.
1847. **Cabry,** Thomas, North Eastern Railway, York.
1847. **Cammell,** Charles, Cyclops Steel Works, Sheffield.
1860. **Cannell,** Fleetwood James, Old Park Iron Works, Wednesbury.
1860. **Carbutt,** Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1856. **Carrett,** William Elliott, Sun Foundry, Leeds.
1858. **Carson,** James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1849. **Chamberlain,** Humphrey, Yarmouth, Isle of Wight.
1857. **Chrimes,** Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1854. **Clark,** Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. **Clark,** George, Monkwearmouth Engine Works, Sunderland.
1859. **Clay,** William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1847. **Clift,** John Edward, Durnford Place, Coventry Road, Birmingham.
1860. **Clunes,** Thomas, Vulcan Iron Works, Worcester.
1847. **Cochrane,** Alexander Brodie, Woodside Iron Works, near Dudley.
1858. **Cochrane,** Charles, Woodside Iron Works, near Dudley.
1860. **Cochrane,** Henry, Ormesby Iron Works, Middlesborough.
1854. **Cochrane,** John, Woodside Iron Works, near Dudley.
1847. **Coke,** Richard George, Mining Engineer, Chesterfield.
1853. **Cooper,** Samuel Thomas, Leeds Iron Works, Leeds.
1860. **Cope,** James, Mining Engineer, Pensnett, near Dudley.
1848. **Corry,** Edward, 8 New Broad Street, London, E.C.
1857. **Cortazzi,** Francis James, Locomotive Superintendent, Great Indian Peninsula Railway, Bombay: (or care of T. D. Hornby, Exchange Buildings, Liverpool.)
1860. **Coulthard,** Hiram Craven, Park Iron Works, Blackburn.
1860. **Cowie,** David, Engine Works, Abo, Finland.
1847. **Cowper,** Edward Alfred, 35A Great George Street, Westminster, S.W.
1853. **Craig,** William Grindley, 14 Cannon Street, London, E.C.
1847. **Crampton,** Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. **Crawhall,** Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.

1857. Criswick, Theophilus, Plymouth Iron Works, Merthyr Tydvil.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, Engineer, West Hetton Collieries, near Ferryhill.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1861. Dixon, Thomas, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Dodds, Thomas W., Holmes Engine Works, Rotherham.
1857. Douglas, George K., Resident Engineer, Birkenhead Railway, Birkenhead.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1856. Dudgeon, John, Sun Iron Works, Millwall, London, E.
1856. Dudgeon, William, Sun Iron Works, Millwall, London, E.
1857. Dunlop, John Macmillan, Marlborough Street, Oxford Street, Manchester.
1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.

1859. Eassie, Peter Boyd, Saw Mills, High Orchard, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1859. Egleston, Thomas, Jun., 10 Fifth Avenue, New York, United States.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, New Cross, Surrey, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.

1857. Fairlie, Robert Francis, 224 Gresham House, Old Broad Street, London, E.C.
1861. Fearnley, Thomas, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1847. Fenton, James, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Fernie, John, Midland Railway, Locomotive Department, Derby.
1861. Field, Joshua, Jun., Cheltenham Place, Lambeth, London, S.
1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.
1847. Fothergill, Benjamin, 65 Cannon Street, London, E C.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1857. Fowler, John, Steam Plough Works, Leeds.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1859. Fraser, John, Resident Engineer, Leeds Bradford and Halifax Junction Railway, Leeds.
1853. Fraser, Joseph Boyes, Alma Place, Kenilworth.
1856. Freeman, Joseph, 22 Cannon Street, London, E.C.
1852. Froude, William, Elmsleigh, Paignton, Torquay.

1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1860. Gibbons, Benjamin, Jun., Athol House, Edgbaston, Birmingham.
1856. Gilkes, Edgar, Tees Engine Works, Middlesborough.
1854. Goode, Benjamin W., St. Paul's Square, Birmingham.
1847. Goodfellow, Benjamin, Hyde Iron Works, Hyde, near Manchester.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., Phœnix Works, Wakefield.
1858. Greenwood, Thomas, Albion Foundry, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.

1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1857. Hall, William, Bloomfield Iron Works, Tipton.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, North Eastern Railway, Newcastle-on-Tyne.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1861. Hawkins, William Bailey, Pontypool Iron Works, Pontypool.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1859. Head, Jeremiah, Walnut Tree Cottage, Battersea Rise, Wandsworth, London, S.W.
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1858. Head, Thomas Howard, Teesdale Iron Works, Stockton-on-Tees.
1853. Headly, James Ind, Eagle Works, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1858. Hedley, John, Resident Engineer, South Hetton Colliery, near Fence Houses.
1848. Hewitson, William Watson, Airedale Foundry, Leeds.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesborough.
1856. Hopkinson, John, Messrs. Wren and Hopkinson, Altrincham Street, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.
1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1858. Horsley, William, Jun., Hartley Engine Works, Seaton Sluice, near North Shields.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1860. Howard, James, Britannia Iron Works, Bedford.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1847. Howell, Joseph, Hawarden Iron Works, Holywell, Flintshire.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1861. Huffam, Frederick Thomas, Messrs. Slaughter Gruning and Co., Avonside Iron Works, Bristol.
1857. Humber, William, Pancras Chambers, Pancras Lane, Bucklersbury, London, E.C.
1859. Hunt, James P., Corngreaves Iron Works, Corngreaves, near Birmingham.
1856. Hunt, Thomas, London and North Western Railway, Locomotive Department, Crewe.
1860. Hurry, Henry C., Engineer, West Midland Railway, Worcester.

1850. Ikin, Jonathan Dickson, 18 Great George Street, Westminster, S. W.
1857. Inshaw, John, Engine Works, Morville Street, Birmingham.

1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.

1860. **Jackson**, Samuel, Cyclops Steel Works, Sheffield.
1858. **Jaffrey**, George William, Hartlepool Iron Works, Hartlepool.
1856. **James**, Jabez, 28A Broadwall, Stamford Street, Lambeth, London, S.
1855. **Jeffcock**, Parkin, Mining Engineer, Midland Road, Derby.
1861. **Jeffcock**, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1857. **Jenkins**, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. **Jessop**, Sydney, Park Steel Works, Sheffield.
1861. **Jessop**, Thomas, Park Steel Works, Sheffield.
1854. **Jobson**, John, Derwent Foundry, Derby.
1847. **Jobson**, Robert, Dudley.
1847. **Johnson**, James, Great Northern Railway, Locomotive Department, Doncaster.
1848. **Johnson**, Richard William, Oldbury Carriage Works, near Birmingham.
1861. **Johnson**, Samuel Waite, Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1849. **Johnson**, William, 166 Buchanan Street, Glasgow.
1855. **Johnson**, William Beckett, St. George's Iron Works, Hulme, Manchester.
1861. **Jones**, Alfred, Herbert's Park Iron Works, Bilston.
1861. **Jones**, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. **Jones**, Edward, Old Park Iron Works, Wednesbury.
1857. **Jones**, John Hodgson, 26 Great George Street, Westminster, S.W.
1853. **Joy**, David, Messrs C. De Bergue and Co., Strangeways Iron Works, Manchester.

1857. **Kay**, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1857. **Kendall**, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near North Shields.
1847. **Kennedy**, James, Cressington Park, Aigburth, Liverpool.
1857. **Kennedy**, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1848. **Kirkham**, John, 109 Euston Road, London, N.W.
1847. **Kirtley**, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1859. **Kitson**, Frederick William, Monkbridge Iron Works, Leeds.
1848. **Kitson**, James, Airedale Foundry, Leeds.
1859. **Kitson**, James, Jun., Monkbridge Iron Works, Leeds.

1860. **Law**, David, Phœnix Iron Works, Glasgow.
1857. **Laybourn**, John, Isca Foundry, Newport, Monmouthshire.
1856. **Laybourn**, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. **Lea**, Henry, Suffolk Works, Berkley Street, Birmingham.

1860. Lee, John, Victoria Foundry, Litchurch, near Derby.
1857. Lees, Sylvester, Locomotive Superintendent, East Lancashire Railway, Bury, Lancashire.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Beehive Mills, Thornton Road, Bradford, Yorkshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Jun., Old Park Iron Works, Wednesbury.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, New Brown Street, Market Street, Manchester.
1859. Lord, Thomas Wilks, 32 Boar Lane, Leeds.
1861. Low, George, Messrs. Williamson Brothers, Canal Iron Works, Kendal.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1856. Mackay, John, Mount Hermon, Drogheda.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Midland Railway, Derby.
1848. Marshall, Edwin, Britannia Carriage Works, Birmingham.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Stourbridge Water Works, Stourbridge.
1860. Marten, George Priestley, Messrs. Stothert and Marten, Steam Ship Works, Bristol.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1857. Masselin, Armand, Spon Lane Glass Works, near Birmingham.
1853. Mathews, William, Corbyn's Hall Iron Works, near Dudley.
1848. Matthew, John, Messrs. John Penn & Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1860. Mayer, Joseph, Iron Ship Builder, Linz, Austria: (or care of William Seyd, 35 Ely Place, Holborn, London, E.C.)
1859. Maylor, William, East Indian Iron Company, Beypoor: (or care of E. J. Burgess, 8 Austin Friars, London, E C.)
1847. McClean, John Robinson, 17 Great George Street, Westminster, S.W.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Vulcan Iron Works, Worcester.

1858. **Meik, Thomas**, Engineer to the River Wear Commissioners, Sunderland.
1857. **Menelaus, William**, Dowlais Iron Works, Merthyr Tydvil.
1857. **Metford, William Ellis**, Flook House, Taunton.
1847. **Middleton, William**, Vulcan Iron Foundry, Summer Lane, Birmingham.
1853. **Miller, George Mackey**, Great Southern and Western Railway, Dublin.
1856. **Mitchell, Charles**, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. **Mitchell, James**, Melrose Cottage, Plumstead Common, near Woolwich, S.E.
1861. **Mitchell, Joseph**, Worsbro' Dale Colliery, near Barnsley.
1859. **Moor, William**, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1849. **Morrison, Robert**, Ouseburn Engine Works, Newcastle-on-Tyne.
1858. **Mountain, Charles George**, Suffolk Works, Berkley Street, Birmingham.
1857. **Muntz, George Frederick**, French Walls, near Birmingham.
1856. **Muntz, George Henri Marc**, Albion Tube Works, Nile Street, Birmingham.
1859. **Murphy, James**, Railway Works, Newport, Monmouthshire.
1858. **Murray, Thomas H.**, Engine Works, Chester-le-Street, near Fence Houses.

1848. **Napier, John**, Vulcan Foundry, Glasgow.
1856. **Napier, Robert**, Vulcan Foundry, Glasgow.
1861. **Natorp, Gustavus**, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
1861. **Naylor, John William**, Wellington Foundry, Leeds.
1858. **Naylor, William**, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1860. **Nettlefold, Joseph Henry**, Screw Works, Broad Street, Birmingham.
1856. **Newall, James**, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1858. **Nichol, Peter Dale**, East Indian Railway, Locomotive Department, Howrah, Calcutta: (or care of Anthony Nichol, Quay Side, Newcastle-on-Tyne.)
1850. **Norris, Richard Stuart**, London and North Western Railway, Engineer's Office, Liverpool.

1860. **Oastler, William**, Engineer, Worcester Gas Works, Worcester.
1847. **Owen, William**, Messrs. Sandford and Owen, Phœnix Works, Rotherham.

1859. **Paquin, Jean François**, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid.
1860. **Parkin, John**, Harvest Lane Steel Works, Sheffield.
1858. **Parkinson, John**, Victoria Brass and Copper Works, Bury, Lancashire.
1847. **Peacock, Richard**, Messrs. Beyer Peacock & Co., Gorton, near Manchester.
1848. **Pearson, John**, 1 Manchester Buildings, Old Hall Street, Liverpool.
1859. **Peet, Henry**, Lancaster and Carlisle Railway, Locomotive Department, Carlisle.
1861. **Perkins, Loftus**, 6 Francis Street, Regent's Square, London, W.C.

1856. Perring, John Shae, 104 King Street, Manchester.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., Eccleston Hall, near Prescot.
1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.
1859. Platt, John, Hartford Iron Works, Oldham.
1861. Plum, Thomas William, Blaenavon Iron Works, near Newport, Monmouthshire.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, West Midland Railway, Worcester.
1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1855. Prideaux, Thomas Symes, 32 Charing Cross, London, S.W.

1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1859. Rennie, George Banks, 39 Wilton Crescent, Belgrave Square, London, S.W.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1848. Robertson, Henry, Shrewsbury and Chester Railway, Shrewsbury.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1858. Robson, Jonathan, Blackwall Engine and Iron Ship Building Works, Gateshead.
1852. Rofe, Henry, Engineer, Birmingham Water Works, Paradise Street, Birmingham.
1851. Rogers, Ebenezer, Abercarn, near Newport, Monmouthshire.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.
1857. Routledge, William, New Bridge Foundry, Salford, Manchester.
1860. Rumble, Thomas William, Atlas Steel Works, Sheffield.
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1859. Ryder, John Northcote, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 28 Cornhill, London, E.C.

1857. Samuelson, Martin, Scott Street Foundry, Hull.
1861. Sanderson, George G., Parkgate Iron Works, Rotherham.
1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1858. Scott, Joseph, Messrs. R. & W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1848. Scott, Michael, 26 Parliament Street, Westminster, S.W.
1861. Scott, Walter Henry, London and North Western Railway, Locomotive Department, Wolverton.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1847. Sinclair, Robert, Eastern Counties Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, Atherstone.
1859. Slater, Isaac, Gloucester Wagon Company, Gloucester.
1853. Slaughter, Edward, Avonside Iron Works, Bristol.
1859. Smith, Charles Frederic Stuart, Mining Engineer, Midland Road, Derby.
1854. Smith, George, Wellington Road, Dudley.
1847. Smith, Henry, Spring Hill Works, Birmingham.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860 Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1859. Smith, Matthew, Fazeley Street Wire Mills, Birmingham.
1860. Smith, Richard, The Priory, Dudley.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1857. Snowdon, Thomas, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1859. Spencer, John Frederic, Bank Buildings, Newcastle-on-Tyne.
1853. Spencer, Thomas, Old Park Works, near Shiffnal.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1857. Stokes, Lingard, Locomotive Superintendent, East Indian Railway, Howrah, Calcutta.
1861. Sumner, William, 36 Faulkner Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cathcart Street, Birkenhead.
1860. Thierry, Eugène, Inspecting Engineer, Russian Railways, 25 Place Vendôme, Paris.
1857. Thompson, John Taylor, Messrs. R. and W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1858. Thomson, William, Jun., Railway Foundry, Normanton.
1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1856. Truss, Thomas, Shrewsbury and Chester Railway, Carriage Department, Chester.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, New Dock Iron Works, Leeds.
1856. Waddington, Thomas, New Dock Iron Works, Leeds.
1861. Walker, John G., Netherton Iron Works, near Dudley.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Iron Works, Burton-on-Trent.
1847. Weallens, William, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.

1860. Weild, William, Messrs. Beyer Peacock & Co., Gorton, near Manchester.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.
1847. Whitworth, Joseph, Chorlton Street, Manchester.
1852. Whytehead, William Keld, Engineer-in-Chief to the Government of Paraguay, 69 Cornhill, London, E.C.
1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, Manchester Sheffield and Lincolnshire Railway, Engineer's Office, London Road, Manchester.
1856. Wilson, Edward, West Midland Railway, Worcester.
1858. Wilson, Edward Brown, 36 Parliament Street, Westminster, S.W.
1859. Wilson, George, Messrs. Cammell and Co., Cyclops Steel Works, Sheffield.
1857. Wilson, John, Spring Works, Hill Top, Westbromwich.
1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 27 Duke Street, Westminster, S.W.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1858. Wood, Nicholas, Hetton Hall, Hetton, near Fence Houses.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Midland Road, Derby.
1861. Woodhouse, William Henry, 23 Parliament Street, Westminster, S.W.
1858. Woods, Hamilton, Messrs. Allsopp and Sons, Burton-on-Trent.
1860. Worssam, Samuel William, King's Road, Chelsea, London, S.W.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Lancaster.
1859. Wright, Joseph, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Works, Tipton Green, Dudley.
1859. Wrigley, Francis, Queen's Chambers, 5 Market Street, Manchester.
1853. Wymer, Francis W., Tyne and Continental Steam Navigation Company, Newcastle-on-Tyne.

1861. Yule, William, Baird's Works, St. Petersburg.

HONORARY MEMBERS.

1848. Branson, George, Belmont Row, Birmingham.
1858. Budden, William Humphryes, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1851. Clare, Thomas Deykin, Carr's Lane, Birmingham.

1848. Crosby, Samuel, Leek Street, Birmingham.
1850. Gwyther, Edwin, Belmont Row, Birmingham.
1857. Hawkes, William, Eagle Foundry, Broad Street, Birmingham.
1860. Hutchinson, William, West Hartlepool.
1858. Lawton, Benjamin C., Grainger Street, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Member.*)
1860. Manby, Cordy, New Street, Dudley.
1856. Pettifor, Joseph, Midland Railway, Derby.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1859. Sherriff, Alexander Clunes, General Manager, West Midland Railway, Worcester.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1861. Williamson, Alexander W., Ph. D., University College, Gower Street, London, W.C.

GRADUATES.

1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
1851. Potts, John Thorpe, 4 Crescent Place, The Grove, Camberwell, Surrey, S.

PROCEEDINGS.

31 JANUARY, 1861.

The FOURTEENTH ANNUAL GENERAL MEETING of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 31st January, 1861; BENJAMIN FOTHERGILL, Esq., Vice-President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1861.

The Council have much pleasure, on this the Fourteenth Anniversary of the Institution, in congratulating the Members on the very satisfactory position and progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1860, shows a balance in the Treasurer's hands of £1109 2*s*. 11*d*., after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1860, and report that the following balance sheet rendered by the Treasurer is correct.

(See Balance Sheet appended.)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the past year; the total number of Members of all classes for the year being 428, of whom 18 are Honorary Members, and 2 are Graduates: 8 are Life Members, 4 of whom have been added during the past year.

The following deceases of Members of the Institution have occurred during the past year 1860 :—

CHARLES COWPER, ...	London.
WILLIAM B. B. HARVEY, . .	Calcutta.
CHARLES MAY, ...	London.
JOSEPH MILLER, ...	Carlisle.
ROBERT B. PRESTON, . . .	Liverpool.
ROBERT RUSSEL, ...	Londonderry.
FRANK W. S. WEST, ...	Calcutta.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year, and expressing their thanks to the donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished.

LIST OF DONATIONS TO THE LIBRARY.

Collection of Engineering Drawings, third part; from the École Impériale des Ponts et Chaussées.

Portrait of Robert Stephenson; from his executors.

Third Report of the Commissioner on the Internal Communications of New South Wales; from Capt. Martindale, R.E.

Report on Railway Works and Railway Extension Contracts in New South Wales; from Capt. Martindale, R.E.

Report of the Commissioner of Patents, United States, 1857 and 1858.

Transactions of the Institution of Civil Engineers of Ireland, from the commencement; from the Institution.

Reports of the Royal Cornwall Polytechnic Society; from the Society.

Journal of the Royal United Service Institution, from the commencement; from the Institution.

Reports of the Association for the Prevention of Steam Boiler Explosions; from Mr. H. W. Harman.

Useful Information for Engineers (second series), by William Fairbairn; from the author.

Elements of Mechanism, by T. M. Goodeve; from the author.

Steam on Common Roads, by C. F. T. Young; from the author.
On the Working and Ventilation of Coal Mines in Northumberland and Durham, by Mr. John Wales; from the author.
Steam Boiler Explosions, by Zerah Colburn; from the author.
On the Thermo-dynamics of Elastic Fluids, by Joseph Gill; from the author.
The Screw Propeller, by Robert Wilson; from the author.
Proceedings of the Institution of Civil Engineers; from the Institution.
Reports of the British Association for the Advancement of Science; from the Association.
Transactions of the French Institution of Civil Engineers; from the Institution.
Transactions of the Institution of Engineers in Scotland; from the Institution.
Transactions of the Royal Scottish Society of Arts; from the Society.
Memoirs of the Literary and Philosophical Society of Manchester; from the Society.
Journal of the Society of Arts; from the Society.
The Engineer; from the Editor.
The Mechanics' Magazine; from the Editor.
The Civil Engineer and Architect's Journal; from the Editor.
The London Journal of Arts; from the Editor.
The Artizan Journal; from the Editor.
The Practical Mechanic's Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Steam Shipping Journal; from the Editor.
Original Drawings of Boulton and Watt's Pumping Engine; from Mr. William D. Burlinson.
Photographs of Westminster New Bridge Works; from Mr. Alexander B. Cochrane and Mr. John Cochrane.
Photograph of Locomotive Boiler; from Mr. George Alton.
Specimens of Ironstone; from Mr. Samuel H. Blackwell.
Specimens of Puddled Bar and Rail made from Cleveland Pig Iron; from Mr. Thomas Snowdon.
Specimen of Railway Chair and Key; from Mr. Edgar Gilkes.

The Council have great satisfaction in referring to the number of Papers that have been brought before the meetings during the past year, and the practical value and interest of many of the communications, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing

papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the meetings during the last year:—

Description of an improved Gas Meter; by Mr. Alexander Allan, of Perth.

On the application of Superheated Steam; by Mr. John N. Ryder, of London.

On Giffard's Injector for feeding steam boilers; by Mr. John Robinson, of Manchester.

On some Regenerative Hot-Blast Stoves, working at a temperature of 1300° Fahrenheit; by Mr. Edward A. Cowper, of London.

On Pinel's Magnetic Water Gauge for steam boilers; by Mr. George Piggott, of Birmingham.

On the Ten Yard Coal of South Staffordshire and the mode of Working; by Mr. William Mathews, of Dudley.

Description of a method of Taking Off the Waste Gases from Blast Furnaces; by Mr. Charles Cochrane, of Middlesborough.

Description of a Machine for Covering Telegraph Wires with India-rubber; by Mr. C. William Siemens, of London.

On the Burning of Coal instead of Coke in Locomotive Engines; by Mr. Charles Markham, of Derby.

Description of Aerts' Water Axlebox; by Mr. Sampson Lloyd, of Wednesbury.

On a new process of Open Coking; by Mr. Samuel H. Blackwell, of Dudley.

Description of a Machine for Drilling instead of Punching wrought iron plates; by Mr. John Cochrane, of Dudley.

Description of the Round Oak Ironworks; by Mr. Frederick Smith, of Brierley Hill.

On the application of the Decimal System of Measurement in Boring and Turning Wheels and Axles; by Mr. John Fernie, of Derby.

Description of Machinery for Crushing Stone for macadamising roads; by Mr. Charles G. Mountain, of Birmingham.

On Taking Off the Waste Gas from Open-Topped Blast Furnaces; by Mr. Samuel Lloyd, of Wednesbury.

Description of a new Safety Coupling for Railway Wagons; by Mr. Charles Markham, of Derby.

Description of a Steam Hammer for Light Forgings; by Mr. Richard Peacock, of Manchester.

The Council have particular pleasure in referring to the great success attending the Annual Provincial Meeting of the Institution in Birmingham last summer, and in expressing their special thanks to the Local Committee and the Honorary Local Secretary, Mr. Walter May, for the excellent reception that was given to the Members of the Institution on that occasion; and they look forward with much confidence to the important advantages arising from the continuance of these Annual Provincial Meetings, from the facilities afforded by them for the personal communication of the Members in different districts of the country, and the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, will go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present annual meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—relative value of radiant surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—incrustation of boilers, and means of prevention—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

Steam Engines—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—

injection and surface condensers—air pumps—governors—valves, bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double-cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm-governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—use of coal—consumption of smoke—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by Gas, or explosive compounds—Electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of the application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to the construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax and other fibrous materials, both in the natural length of staple and when cut.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

LATHES, PLANING, BORING, DRILLING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders.

STEAM HAMMERS, improvements in construction, and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto

FIRE ENGINES, hand and steam, ditto ditto ditto

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto

CRANES, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction and results of working.

COFFER DAMS AND PILING, facts relating to the construction—cast iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast iron and wrought iron, ditto ditto

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, consumption of fuel in different kinds—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—means and results of application of waste gas from close-topped and open-topped furnaces.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS, and FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking—mixtures of coal slack and other materials—evaporative power of different varieties.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of solid wrought iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

The communications should be written on foolscap paper, on one side only of each page, leaving a clear margin on the left side for binding, and they should be written in the third person. The drawings illustrating the paper should be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper; or enlarged diagrams should be added for the illustration of any particular portions: the scale of each drawing to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31st December, 1860.

Cr.	£	s.	d.
By Balance 31st December, 1859	713	16	11
,, Subscriptions from 26 Members in arrear	78	0	0
,, ditto from 359 Members for 1860	1077	0	0
,, ditto from 4 Members in advance for 1861	12	0	0
,, ditto from 4 Life Members	120	0	0
,, ditto from 2 Graduates for 1860	4	0	0
,, Entrance Fees from 57 New Members	114	0	0
,, Sale of Extra Reports	17	19	6
,, Interest from Bank	21	11	11
	£2158	8	4

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	356	4	6			
Less Authors' copies of papers, repaid	39	8	6	316	16	0
,, Stationery and Printing				65	1	7
,, Office Expenses and Petty Disbursements				32	2	3
,, Expenses of Meetings				16	1	6
,, Fittings, Furniture, and Repairs				6	6	5
,, Travelling Expenses				5	9	6
,, Parcels				3	8	8
,, Postages				35	12	0
,, Salaries				450	0	0
,, Rent and Taxes				118	7	6
,, Balance 31st December, 1860				1109	2	11
				£2158	8	4

(Signed) EDWARD JONES,
SAMPSON LLOYD, } Finance Committee.

31*st January*, 1861.

The CHAIRMAN moved that the Report of the Council be received and adopted, which was passed: he congratulated the Members on the flourishing position and successful progress of the Institution, and thought it was highly gratifying to see the continued increase in the number of Members and in the prosperity of the Institution.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were duly elected for the ensuing year:—

PRESIDENT.

SIR WILLIAM G. ARMSTRONG, . Newcastle-on-Tyne.

VICE-PRESIDENTS.

ALEXANDER B. COCHRANE, . Dudley.
JAMES FENTON, ... Low Moor.
HENRY MAUDSLAY, . . . London.
JOHN PENN, ... London.
JOHN RAMSBOTTOM, . . Crewe.
JOSEPH WHITWORTH, . . . Manchester.

COUNCIL.

JOHN ANDERSON, . . . Woolwich.
CHARLES F. BEYER, . . . Manchester.
ROBERT HAWTHORN, . . Newcastle-on-Tyne.
JAMES KITSON, ... Leeds.
WALTER MAY, . . . Birmingham.
WILLIAM WEALLENS, . . Newcastle-on-Tyne.

Members of Council remaining in office.

ALEXANDER ALLAN, . . Perth.
WILLIAM E. CARRETT, . . Leeds.
EDWARD A. COWPER, . . London.
JOHN FERNIE, ... Derby.
EDWARD JONES, . . . Wednesbury.
SAMPSON LLOYD, . . . Wednesbury.
C. WILLIAM SIEMENS, . . London.
EDWARD WILSON, . . . Worcester.
NICHOLAS WOOD, . . . Hetton.

TREASURER.

Henry Edmunds, . . .	Birmingham.

SECRETARY.

William P. Marshall, . .	Birmingham.

The following New Members were also elected :—

MEMBERS.

Charles Denton Abel, . .	London.
Harry W. Armitage, . .	Leeds.
Henry Brierly, . . .	Manchester.
Charles Dutton, . . .	Westbromwich.
Daniel Joseph Fleetwood, .	Birmingham.
Edward Forster, . . .	Westbromwich.
Alfred Jones, ...	Bilston.
Robert Charles May, . .	London.
Robert Porter, . . .	Birmingham.
George G. Sanderson, . .	Rotherham.
James Tangye, ...	Birmingham.
John G. Walker, . .	Dudley.

HONORARY MEMBER.

Charles Ratcliff, . . .	Birmingham.

The following paper was then read :—

DESCRIPTION OF THE BUDA WROUGHT IRON LIGHTHOUSE.

BY MR. JOHN H. PORTER, OF BIRMINGHAM.

The small map accompanying the drawings of the Buda Wrought Iron Lighthouse, Fig. 2, Plate 2, represents the outline of the land near the mouths of the river Ebro on the eastern coast of Spain. It will be seen that by the peculiarity of the outline of this portion of the coast two natural harbours of refuge are formed: that lying to the north is called Fangal, and that to the south Alfaques. Midway between these the river Ebro flows in two channels to the sea. Dividing these two channels of the Ebro, and formed mainly by the detritus brought down by its waters, lies the flat delta called the island of Buda.

The almost unvarying level of the Mediterranean is here bounded by a coast so flat as to offer but slight landmarks for the guidance of mariners seeking the mouths of the Ebro or the harbours of Fangal and Alfaques. The Spanish government have determined to erect in this locality three lighthouses: a leading or principal light of the second order upon the north eastern extremity of the island of Buda, as shown on the map; a light of the third order upon the point of Baña covering the harbour of Alfaques; and one of the sixth order upon the point of Fangal protecting the harbour of that name. The two smaller are fixed lights, while that of the Buda lighthouse is a revolving light visible at a distance of twenty miles and producing bright flashes at intervals of a minute. The lighting apparatus together with the lanterns and light rooms for these lighthouses are being manufactured by Messrs. Chance, who have kindly furnished the writer with some details of their construction, that this description of the Buda lighthouse may be the more complete. The general designs for these lighthouses were furnished by Don Lucio del Vallé,

of the corps of Royal Engineers of Spain; and the details of the construction submitted by the writer for his approval were referred to the Direction of Public Works in Spain for their sanction.

The Buda lighthouse will be erected on the margin of the sea, not actually in the water, but so close that in very stormy weather its base may be washed by the sea and spray. Owing to the sandy nature of the ground Mitchell's screw piles are adopted for the foundation: eight of them are arranged in an octagon of 56 feet diameter and a ninth is placed in the centre. Upon the top of the piles, starting at about 3 feet above the level of the sea, is an octagonal pyramidal structure of open ironwork, 150 feet high from the top of the piles to the level of the lantern platform at the summit, as shown in the general elevation, Fig. 1, Plate 1.

From the centre pile rises a hollow cast iron column to a height of 31 feet, from which point radiate the beams that support the platform of the dome-shaped dwelling house. To protect this platform from the violence of the wind, which might otherwise act with great force upon its under surface, an inverted cone is constructed beneath, serving also as a receptacle for stores. This cone was suggested by a similar arrangement adopted in the construction of the small screw-pile lighthouses on our own coasts, such as the Maplin Sand lighthouse near the mouth of the Thames, erected about twenty years ago. From the house platform, rising through the dome to the lantern platform at the summit, is a wrought iron cylindrical tower enclosing the winding staircase by which the keepers ascend to the light.

From the eight external piles rise eight wrought iron pillars, converging from an octagon of 56 feet diameter at the base to one of 9 feet 10 inches diameter at the summit. The nine supports are united horizontally at ten points in the height of the structure by sets of horizontal framing adapted for resisting compression or extension, the intersection of which with the uprights forms thus a series of quadrilateral spaces in the sides of the octagonal pyramid; and these spaces are crossed diagonally by round tie rods, which are united in a centre ring to admit of being screwed up to a state of tension. Other

tie rods radiate obliquely from the central tower to the external uprights, each fitted with a right and left handed screw coupling, and are attached to the tower midway between the tiers of horizontal framing; eight of them ascend and eight descend to the junctions of the framings with the corner pillars. The eight ascending rods thus form in connexion with the horizontal framing under compression a system of trussing analogous to that commonly employed in the interior of gasholders, and so distribute their portion of the central load upon the external supports. By this arrangement the weight of the central tower and stairs is sustained at intervals in the height of the structure by the eight corner pillars, and but slightly by the dome or by the centre pile. The sets of eight descending rods assist with other portions of the structure in preventing any distortion of the general fabric.

The total weight of the superstructure including the lantern is about 170 tons; of which about 40 tons are upon the centre pile, leaving from 16 to 17 tons to be borne by each of the eight corner piles. The ground in which the foundations have to be placed is indeed a sandbank which is gradually extending itself seawards; and although there are the most satisfactory proofs of the sustaining or resisting powers of the screw piles under similar circumstances, it was thought well to have ample margin for contingencies; and while making the superstructure as light as possible, consistently with a due regard to stability, to secure by means of a maximum of screw surface and strength of pile a safeguard against inequalities in the density of the sand. The sustaining power of the screw piles in a foundation of sand has been found to be equal in tons to six times the square of the diameter of the screw in feet; and it is considered that a load in tons of at least five times the square of the diameter in feet can with perfect safety be placed upon a screw pile under such circumstances. This in the case of a screw of 4 feet diameter amounts to 80 tons.

For the Buda lighthouse the screws are 4 feet diameter, and are fixed upon piles of 8 inches diameter entering 30 feet into the sand, as shown in Fig. 1, Plate 1, and enlarged in Figs. 9 and 12, Plate 3. The piles A are solid, of hammered iron, forged in one length; the

upper ends, Fig. 11, are reduced to 7 inches diameter for a length of 22 inches, at which point a collar is welded to the body of the 8 inch pile, on which rests the cast iron cap B. Figs. 8 to 11, Plate 3, show the mode in which the wrought iron corner pillars C are stepped upon the pile caps B in connexion with the horizontal framing of girders D at the base.

The arrangement of the horizontal framing of girders at the base is shown in plan by the diagram, Fig. 3, Plate 2: Fig. 28, Plate 6, shows an enlarged section of the girders that radiate from the centre and of those that form the sides of the octagon; and Fig. 29 is a section of the bracing girders which are framed between the larger girders and form the inner octagons. The girders having no load to sustain are made with but small sectional area in their upper and lower flanges. Depth was considered of importance, as affording surface for rivetting or bolting to the flanges of the corner pillars, and as securing a rigid framework at the base, which, together with the superincumbent weight thus immoveably imposed, should prevent any lateral stress upon the piles. Moreover these systems of rigid horizontal framing tend, in conjunction with the several pillars they are so completely connected with, to relieve any single pile which from an unexpected weakness in its foundation of sand might stand in need of such assistance: a contingency however scarcely to be supposed probable, when the dimensions of the screw and the comparative insignificance of the load are considered. The girders of the base are of puddled steel, manufactured by the Mersey Steel and Iron Company, which it is believed will be less affected by corrosion from the action of the sea water and atmosphere than ordinary iron; and since, with a view to rigidity in this framework of girders, considerable surface occurs, it has been thought desirable to employ a material of closer texture and more highly carbonised than ordinary wrought iron; the more so, because with it is obtained also a superior strength and toughness.

The connexion of the radiating girders of this framing with the centre pile cap and with the cast iron column springing from it is shown in Figs. 13 and 15, Plate 4, and enlarged in Figs. 21 and 22, Plate 5, which refer also to the connexion of corresponding girders in

the succeeding stage of horizontal framing, from which springs the base of the cone below the house platform. The junctions of the cast iron column are all bored, turned, and faced in the lathe.

Although in the only other structure of this nature at all comparable in point of dimensions, namely the screw-pile lighthouse erected by the government of the United States upon the Florida Reef, the principal supports consist of cast iron tubes, it was considered that wrought iron was preferable for the pillars of the Buda lighthouse. It was thought that for such a purpose there was an insecurity in so brittle a material as cast iron; that it was less fitted to undergo the vibration or tremor which occasionally and perhaps to a certain extent generally will pervade a structure of this character and of these dimensions: added to which was a consideration of the inconvenience that would result from the breakage of any of the cast iron tubes in transit, in trans-shipment, or in erection abroad. Wrought iron was therefore determined upon, and next came the consideration of the best form in which to employ it. The tubular form, whether circular or angular, was considered to have a disadvantage in not affording the means of protecting the interior surface of the iron tube from corrosion. It was not considered an economical form in construction for such dimensions as the circumstances seemed to require. The connexions of the several lengths of a pillar with each other and with the horizontal and other framing seemed to be attended with more expense and less simplicity in detail than was desirable. The solid circular form was not open to the first of these objections: on the contrary it presented a minimum of surface for exposure to oxidation and for the wind to act upon, both points of advantage. But the weight of the material as an element in the cost, considering the dimensions that would have been necessary, would have been a maximum, and the price of the bars per ton considerably beyond that of ordinary sizes of bars or plates: and no method of connecting the several lengths seemed economical enough to counterbalance the effect of the first cost of the bars. The actual expense so far would however have been considered comparatively unimportant in the face of the

two advantages already cited; but beyond the desiderata of immunity from oxidation and a minimum of exposure to the wind, one of equal importance was that of convenient surfaces for the attachment in an immoveably rigid manner of the series of horizontal frames, as well as simplicity of connexion for the tension bars of the exterior and centre. The provision of these essential points with a solid bar of at least some 5 or 6 inches diameter seemed attended with considerable expense: clips and collars, as employed in structures upon a smaller scale, being considered insufficient.

The form shown in the enlarged sections, Figs. 25 and 26, Plate 6, produced by rivetting an obtuse-angled angle iron on either side of a wide flat bar, seemed to combine simplicity and economy in the manufacture and in the longitudinal connexions, with lateral stiffness in the pillar itself and with the desired facility of rigid connexion with the other portions of the structure. This form was ultimately adopted in preference to the solid circular form shown in Fig. 27. The angle formed by the two angle irons rivetted to the flat bar corresponds with the angle of the octagon; thus while the centre bar presents a convenient and substantial connexion for the radiating girders, the side flanges afford in like manner a convenient and rigid attachment for those of the octagonal frames.

The larger section of pillar, Fig. 25, Plate 6, consists of a bar 12 inches by 1 inch, with angle irons of 4 inches by 5 inches and ¾ inch thick united to it by 1 inch rivets spaced 6 inches apart. This section is carried up to a height of 5 feet above the level of the house platform, from which point the smaller section is employed, as shown in Fig. 26. This differs from the former only in the centre bar, which is reduced to 9 inches in width. There is thus no portion of the pillar of a less thickness than ¾ inch, and all parts of it can be conveniently inspected after erection, and carefully scraped and repainted when necessary. The surface exposed to the wind is insignificant considering the bracing of the fabric generally. The flanged structure of the pillar itself contributes greatly to its stiffness in all directions, while its sectional area of 24 square inches in the lower portion and 21 square inches in the upper is far more than necessary for resisting the forces that compress it in the direction of

its length. The connexion of the several lengths of the pillar is very simple: the angle irons break joint 6 feet, passing respectively 3 feet above and below the meeting of the ends of the centre bar, and cover plates 3 feet long are used at the junctions of the angle irons and of the centre bar.

The mode of attachment of the horizontal girders to the corner pillars is shown in Figs. 17 to 20, Plate 5, in two different stages of horizontal framing. Figs. 17 and 18 show the attachment in the second stage of horizontal framing, midway between the base and the house platform, the arrangement of the girders being similar to that shown in the diagram, Fig. 3, Plate 2. Figs. 19 and 20 show the attachment immediately above the house dome, where the arrangement of the framing is as shown in the plan, Fig. 4. Similar arrangements of horizontal framing are adopted for the succeeding stages above, with slight modifications as the diameters lessen; Fig. 5 representing the smallest, at the top. Enlarged sections of the bars that compose these frames are given in Figs. 34 to 40, Plate 6: Figs. 34 to 37 corresponding with the plan, Fig. 4, Plate 2, above the house platform; and Figs. 38 to 40 with the plan, Fig. 5, at the top. The curved braces that surround the central staircase tower in the horizontal framework are of angle iron, Figs. 37 and 40, Plate 6, as are also those that connect the radiating beams with the exterior octagonal frame.

Fig. 6, Plate 2, is a diagram of the arrangement of the girders in the house platform, enlarged sections of which are given in Figs. 31 to 33, Plate 6. Fig. 31 is a section of the radiating girders, the connexion of which with the top of the cast iron centre column is shown in Figs. 13 and 14, Plate 4. Fig. 32 is a section of the girders connecting the eight corner pillars and receiving the ends of the intermediate radiating girders. Fig. 33 is a section of the girder at the base of the dome, having the web plate carried up above the level of the platform for the purpose of excluding from the floor of the house the rain water that will fall upon the platform without. Fig. 30 is a section of one of the ribs of the house dome.

The reasons for adopting the dome form for the dwelling house were that the eight ribs of the dome, braced by horizontal framing between and by the radiating beams of an upper floor, assist in sustaining and transferring to the corner pillars a portion of the weight of the central staircase tower and stairs, which otherwise would augment the load upon the centre pile. The dome also presents a small amount of surface in any one plane for the wind to act upon; and is a form well fitted to resist a shock: it admits of the attachment of stays or braces between the ribs and the corner pillars of the lighthouse, as shown in Fig. 1, Plate 1, in such a way as to constitute with the radiating beams of the upper floor a system of horizontal bracing, which contributes to the support of the corner pillars and of the dome itself. Between the ribs of the dome horizontal purlins of iron and timber receive the external covering of corrugated galvanized iron and the inner lining of match boarding, a space of 4 inches being left between the two as a non-conductor. At the crown of the dome and surrounding the staircase tower a raised skylight fitted with moveable louvre boards, Fig. 1, admits light to the small upper rooms and affords ventilation, with an exit for the air that in hot weather may become heated between the inner and outer covering; this heated air will the more rapidly pass away, as small apertures near the base of the dome give admission to a cooler draught. The cone beneath the house consists of eight ribs E, Fig. 13, Plate 4, of $\frac{3}{8}$ inch plate 8 inches wide with angle irons rivetted to its edge of a suitable angle for the octagonal form; eight intermediate ribs of T iron 3 inches by 6 inches are placed between, and the spaces are filled by plate iron $\frac{3}{16}$ inch thick, stiffened with horizontal angle irons. Within this cone, upon a set-off F cast upon the central column, a wrought plate iron ring receives small joists of angle iron G in pairs, rivetted at their outer extremities to the principal ribs of the cone; and between these joist bars are fitted light chequered plates of cast iron to form a flooring.

From the house platform immediately above the cast iron centre column rises the cylindrical tower, $6\frac{1}{2}$ feet diameter, containing the circular stairs, Fig. 1, Plate 1. It is constructed of plate iron $\frac{1}{4}$ inch

thick, and above the dome of the house the plates are 8 feet 2 inches in length, placed vertically, two such lengths corresponding to the distance of 16 feet 4 inches from centre to centre of the successive stages of horizontal framing. Six plates in width form the circumference of the cylinder. The edges of the plates are butted on all sides, with cover strips on the exterior: those covering the horizontal joints are 6 inches wide by $\frac{5}{8}$ inch thick, and those of the vertical joints 4 inches by $\frac{3}{8}$ inch. Figs. 23 and 24, Plate 5, show the attachment of the horizontal radiating girders to the staircase tower, and the eight ribs of the house dome are connected to it by a similar attachment. The circular or winding stairs within the tower are of cast iron, the risers and treads in distinct castings, each having an eye or ring socketing into the other, and strung upon a central tube of wrought iron 2 inches diameter: the outer sides of the treads are bolted to the plating of the tower by four $\frac{1}{2}$ inch bolts and nuts. At every revolution of the stairs a double tread or landing occurs; and in the three upper landings, at a distance of 2 feet 7 inches from the centre, apertures of 6 inches diameter are made for the descent of the weight connected with the clockwork of the lighting apparatus.

The lighting apparatus is fixed upon a pedestal exactly over the centre of the staircase tower, and its weight being considerable is supported by four plate iron beams of 15 inches depth passing right across, rivetted by angle plates to the tower, and secured at their outer extremities between the angle irons of the external corner pillars. The diagram plan, Fig. 7, Plate 2, shows the arrangement of the principal framing of the lantern platform. The curved lines within the angles of the four radiating beams at the centre represent the upper angle irons diverted from the webs for the purpose of stiffening this portion of the work, and with the addition of a wrought iron plate rivetted over all, as shown by the dotted lines, providing a support for the pedestal of the light. Four short beams of the same depth also connect the tower with the four remaining corner pillars. The angle irons of these eight beams are continued outwards beyond the corner pillars to an octagon frame of 18 feet diameter, which with the open wrought iron railing surmounting it forms the boundary of the lantern platform, as shown

in Fig. 1, Plate 1. The portion of the platform extending beyond the eight corner pillars is supported by eight curved T iron brackets, Fig. 1, strongly connected between the angle irons of the pillars. The flooring of the lantern platform is of wrought iron chequered plates $\frac{5}{16}$ inch thick, rivetted down upon the radiating beams, upon the horizontal octagonal framing, and upon an angle iron ring that surrounds the upper edge of the staircase tower.

On the lantern platform is the light room, Fig. 1, Plate 1, 7 feet high, composed of twelve cast iron panels. On the top of these panels is fixed a cast iron soleplate which projects about 12 inches on the outside all round, forming a narrow path for the convenience of the light keepers in cleaning the lantern. The lantern is 8 feet high and composed of twelve gun-metal stanchions bearing a gun-metal cornice, upon which is placed a double dome of copper fixed upon eight gun-metal rafters. The lighting apparatus is a revolving light of the dioptric kind, commonly known as Fresnel's system; and is of the size known as the second order.

Referring to the general construction and details of the lighthouse as now described, it has to be remarked that in addition to a rigid connexion of all parts of the structure it was necessary to have regard to simplicity, convenience, and safety in the process of erecting abroad. With this object the jointing of the several lengths of the external corner pillars is arranged so as to admit of each stage or tier of horizontal framework being permanently attached to the pillars at a distance of 5 feet below the centres of their joints. The lower angle iron coverplate is thereby some 6 inches clear above the horizontal framing, each stage of which thus affords, with the addition of some scaffold boards, a most secure and convenient platform to place the materials on for proceeding with the erection of the succeeding lengths of the external pillars and central tower. The junctions of these parts of the structure can there be conveniently rivetted and bolted, the diagonal tie rods attached and their degree of tension adjusted with accuracy. This self-contained substantial scaffolding is found to be one of the most satisfactory features in the design; and the central staircase tower being raised in cylinders of

8 feet 2 inches length, answering to a complete revolution of the stairs, and two such lengths corresponding exactly with the spacing of each tier of framing and ties above the house dome, a permanent and secure means of ascending and descending is provided as the work proceeds: the small window openings admitting at the same time of a man passing through the side of the tower to the platform of framing next below it. This special advantage will moreover always exist for the inspection of all parts of the structure, affording the same convenience for painting when occasion requires.

Mr. PORTER observed that in the general appearance of the lighthouse the cone under the house platform might perhaps convey the idea of concentrating the weight of the structure upon the centre pile; but this was not the case, the sole object of the conical form being to break the upward force of wind underneath the flooring, and the ribs of the cone were simply to stiffen the plates of which it was composed. Even the central tower containing the staircase was only partially carried by the centre pile, the weight being mainly transferred to the eight outside pillars of the lighthouse by the diagonal trussing at each of the horizontal framings; and by this mode of construction there was abundant sustaining power for carrying the entire weight of the staircase tower, even if the centre pile were removed.

Mr. J. FENTON observed that the main horizontal beams in each course of framing appeared to be constructed in the form of girders, though described as merely ties between the corner pillars; and he enquired what was the reason for adopting the girder form, instead of a simple tube with a bolt through it, which he thought would have been the direct mode of resisting the strain of both compression and tension to which they were exposed.

Mr. PORTER said the horizontal beams were not girders really, as there was no load upon them, but were merely struts and ties between the corner pillars; but the girder form of construction, as shown in the drawings, was adopted for convenience of make, and because it afforded room for convenient attachment to the other parts of the

framing by rivetting. The depth obtained by the girder form had also the advantage of adding to the diagonal stiffness of each face of the lighthouse, by increasing the rigidity of the junctions with the corner pillars: and the radiating girders in each tier of horizontal framing were also made of the same deep form, to increase the resistance to transverse vibration.

Mr. E. A. Cowper had been concerned in the construction of several wrought iron lighthouses of smaller size, amongst others the Mucking and Sea Reach lighthouses near the mouth of the Thames, made at Messrs. Fox Henderson and Co.'s works, in which the corner pillars were hollow cylinders of wrought iron, about 10 inches diameter, constructed of $\frac{3}{8}$ inch plates bent round and rivetted together with a butt joint. That made a neat looking construction, but it was certainly expensive, and almost impossible to paint inside: in the construction now described the entire surface was exposed to view and accessible for painting. He thought the section of the main pillars seemed rather light, considering the great height of the structure; probably some metal might have been spared out of the horizontal framings and added in the pillars with advantage.

The diagonal bracing was a most excellent system, and an essential provision in such a construction. The Maplin Sand lighthouse was originally designed without diagonal stays; but when erected it was found that, though strong enough vertically, the whole rocked and twisted round horizontally when a moderate force was exerted at the top of any one of the pillars at regular intervals, so as to get into time with the vibration of the structure; such a motion might have proved fatal to its stability, and diagonal stays were therefore added, as in the lighthouse now described, which entirely corrected the defect. He thought the screw piles would prove a valuable means of conveniently obtaining a good foundation in sand; but would have preferred however a strong heavy cast iron sill at the bottom, bedded in a mass of concrete, for the pillars to stand in, with the addition of strong diagonal braces starting from the sill. In the Bishop's Rock lighthouse near the Land's End, constructed of a framework with cast iron corner pillars, there was no diagonal bracing for the first 12 feet high, so that in a storm shortly after it was erected the whole

lighthouse had twisted round and the pillars broke off at the base. A stone lighthouse was now being built in its place at a greatly increased cost, whereas the original iron structure might have been made thoroughly satisfactory and secure, if it had been properly stiffened with diagonal stays starting from the very foundation.

Mr. J. Cochrane thought there was not any better system of bracing than that shown in the drawings, in which it appeared to be well carried out; but he would prefer to have it begin from the very bottom, by the addition of diagonal braces between the piles, as had been suggested. The Sydenham water towers were constructed in a similar manner, only that instead of horizontal bracing a horizontal wrought iron diaphragm or annular plate 3 feet wide was fixed at each tier between the joints of the columns, which served to stiffen the whole structure, and vertical diagonal bracing was used as well. He enquired what saving of metal was effected by the use of puddled steel instead of iron in the lowest tier of the lighthouse.

Mr. Porter replied that the weight was about 25 or 30 per cent. less with the puddled steel than it would have been with iron, for the same strength. The foundation piles rose only about 3 feet above the surface of the ground, and then the lowest tier of horizontal framing had the effect of staying the heads of the piles and preventing any racking or twisting, so that it had not appeared necessary to add any diagonal bracing between the piles.

Mr. A. Masselin thought the construction of the framing was rather too light for so high a structure, and there would be a considerable vibration at the top: he had felt even stone lighthouses vibrate in a gale more than was pleasant, and feared the effect of the wind would be greater in the present instance, with a heavy weight on the top of such a high and light tower. The highest iron lighthouse previously erected that he knew of was only 112 feet high, but this was 150 feet high; and the weight of the lantern and apparatus at the top would be fully 10 tons, which he thought would produce a great tremor on all the joints in a storm of wind, having a tendency to make it insecure after some years' exposure. Although not erected actually in the water, the lighthouse was so near the shore as to be within reach of the water in a gale; and there might be a possibility of a wreck or a

piece of timber being carried against one of the horizontal struts or one of the corner pillars, and breaking it by the violence of the blow, when there would be imminent danger for the whole structure. He fully concurred in the importance of the diagonal tie rods, but thought they were rather small in section, being only 1¼ and 1 inch diameter; and if a few were, to give way from corrosion or otherwise, he feared the remainder would suffer.

For the lantern platform at top he thought an inverted cone was as desirable as for the house platform at bottom, to break the upward force of the wind; and this would also improve the appearance by making it look less slender at the top. The lantern or light room was a 12 sided figure, with alternate large sides about 3½ feet wide by 7 feet high, thus presenting a large surface for the wind to act upon.

Mr. F. J. Bramwell remarked that the stiffness of the mode of construction adopted in the lighthouse was shown by the experience of the Crumlin viaduct in South Wales, which was 200 feet high with a number of spans of 150 feet each, the railway being carried on four Warren's truss girders: the piers were built of slender cast iron columns with diagonal bracing, of so light a construction that they appeared at first more like temporary scaffolding than permanent piers, and the appearance of the lighthouse closely resembled them. The weight of the girders and the passage of trains on the viaduct must produce as great a stress upon the piers, he thought, as the lantern would on the top of the lighthouse of only three quarters the height, and the action of the wind would be the same in both cases; but the viaduct had stood secure since first erected several years ago, and therefore he did not see any cause for alarm in the slender appearance of the lighthouse. The only material difference that he noticed was that the piers at Crumlin were fixed on the solid rock, instead of on piles sunk in sand.

Mr. C. Markham considered the Crumlin viaduct was not an analogous case to the lighthouse, but differed from the latter in having the piers all tied together longitudinally by the girders resting on the top of them, which effectually prevented any vibration of the piers under the rolling motion of the trains; whereas the lighthouse was an

isolated tower, carrying a heavy weight at a great height without being steadied by any extraneous support.

Mr. F. J. Bramwell observed that although the piers in the Crumlin viaduct were strengthened in the longitudinal direction by the girders at top, these did not afford any aid in sustaining them laterally; and in this direction therefore the piers were in as exposed a condition as the lighthouse, being subjected to the full action of the wind when blowing up or down the valley crossed by the viaduct, while the girders at top presented so much additional surface to the wind.

Mr. J. Fernie enquired how the several lengths of the main corner pillars in the lighthouse were connected together at the junctions, so as not to cause any diminution of strength at those parts.

Mr. Porter replied that the joint of one of the angle irons composing the pillar was made 3 feet below the joint of the middle plate, and that of the other angle iron 3 feet above; cover plates 3 feet long were added on the face of each angle iron at the joints, and a pair of the same length at the joint of the middle plate, making the joints as strong as the rest of the pillar. There was now about 100 feet height erected at the works, which the members would be able to see on the following day.

The Chairman thought the paper was one of much interest and value, describing the practical application of open wrought iron work in a structure of such importance and magnitude. In connexion with this subject he hoped they might be able to obtain a paper on the mechanical arrangements adopted at the present time in the lighting of lighthouses. He proposed a vote of thanks to Mr. Porter for his paper, which was passed.*

The following paper, communicated through Mr. Edward Jones of Wednesbury, was then read :—

* Since the meeting, and in consequence of the suggestion then made in the discussion, a horizontal framing of wrought iron girders has been added, fixed to the piles at 3 feet below the surface of the sand, and similar in construction to that at the tops of the piles.

ON BENSON'S HIGH PRESSURE STEAM BOILER.

BY MR. JOHN JAMES RUSSELL, OF WEDNESBURY.

The boiler forming the subject of the present paper, the invention of Mr. Martin Benson of Cincinnati, U.S., was described at a former meeting of the Institution, in a paper giving the particulars of the application and working of a number of these boilers in America, where they have been in operation from three to four years and about 50 of them are in use for various purposes. (See Proceedings Inst. M. E., Nov. 1859.)

A boiler of this construction having since been erected at the writer's works at Wednesbury, and having now worked satisfactorily for ten months, the further results are given in the present paper. This boiler has been in constant work during the whole of the time with entire success, driving an engine of 60 indicated horse power; and the writer has been so thoroughly satisfied with the results and the correctness of the principle upon which the boiler is constructed that he has since erected a second and larger one upon the same plan, but with some improvements in the details of construction, results of experience derived from the former boiler. This boiler is now at work on the same premises, and is shown in Figs. 1, 2, and 3, Plate 7. Fig. 1 is a front elevation, showing the receiver and circulating pump; Fig. 2 is a longitudinal section of the boiler, and Fig. 3 a transverse section at right angles to Fig. 2.

The boiler proper is composed entirely of tubes A, Fig. 2, arranged in a series of horizontal rows over the fire. BB are doorways at the front and back of the boiler for fixing, disconnecting, and taking out the tubes. C, Fig. 1, is the water and steam receiver: D the circulating pump, which draws its supply of water from the receiver C and is worked by the small donkey engine E above. F is the main supply

pipe from the circulating pump, to which the lowest tubes of each section of the boiler are connected. G is the main delivery pipe, to which the top tubes of each section are joined, and into which the water and steam together are delivered from the tubes and thence discharged into the upper part of the receiver C.

The circulating pump D is shown enlarged in Fig. 10, Plate 9, and is a simple direct-acting pump with a metallic packed piston; constructed with a single slide valve H instead of suction and delivery valves, so that it is certain and constant in its action; the slide valve is made without any lap or lead, and thus agrees exactly with the motion of the piston. The pump draws its supply of water from the receiver through the ordinary exhaust port I running round the cylinder, and discharges it by the outlet pipe K, forcing it into the tubes through the pipe F, Fig. 1. The steam generated in the tubes is driven up with the water through the tubes and discharged through the pipe G into the receiver C, where the steam and water are separated; and the water is then again taken by the circulating pump and returned into the tubes. In starting the boiler the receiver is supplied with water until its level reaches the fifth or sixth row of tubes from the bottom, as shown by the dotted line in Fig. 1; as the circulating pump is standing still at first in consequence of having no steam to work it, the slide valve H, Fig. 10, is allowed to be lifted off its face by the pressure of the water, and lets the water flow past the pump direct through into the tubes. The fire is then lighted and steam raised from the water in the tubes, which starts the circulating pump to work.

More water is forced through the tubes by the circulating pump than is evaporated in them. The circulating pump of the boiler now used for ten months is double-acting, 6 inches in diameter with 9 inches stroke, and makes 40 revolutions per minute against a resistance of from 7 to 10 lbs. pressure per square inch; the power required to work it is therefore about $\frac{1}{4}$ horse power including the friction of the pump. At this speed it forces through the boiler from 9 to 11 times as much water as is evaporated, which has been found too much to get the greatest efficiency of the boiler; and from 6 to 8 times the quantity evaporated is considered about the proper proportion. In

this instance owing to the construction of the donkey engine the pump cannot be worked at less than 40 revolutions per minute, at which speed it is fully capable of supplying a 100 horse power boiler at ordinary working pressures, instead of one of only 60 horse power. With high pressure steam superheated and worked expansively, the pump is large enough for a 150 horse power boiler, in which case $\frac{1}{3}$rd per cent. or $\frac{1}{300}$th of the whole power produced is all that is required for working the circulating pump; and with the improved circular bends that have now been adopted for uniting the ends of the tubes in the boiler there is reason to expect the circulation can be maintained with much less power. No more power is required to work the pump with 80 and 100 lbs. steam than with 20 lbs., since the pressure is the same on both sides of the piston and the only resistance to be overcome is the friction of the water in the tubes, which of course is increased in proportion to the speed; with the boiler now at work the resistance on the piston at the proper speed does not exceed 7 to 10 lbs. per square inch. Originally the delivery pipe G, Fig. 2, into which the steam and water from the tubes are discharged, was only 5 inches diameter inside, which was found too small; in the present boiler it has been made 10 inches diameter. The receiver C is supplied with feed water by one of Giffard's injectors L, Fig. 1, instead of an ordinary feed pump.

It was originally supposed that the mechanical circulation of the water with 9 to 11 times more water forced through the tubes than is evaporated would be sufficient to prevent deposit, by keeping them washed out clean; and this is the case to a certain extent, as all loose matter is washed by the circulation from the tubes into the receiver. Some incrustation however does take place, but not sufficient to present any practical difficulty or cause any damage to the tubes. One of the tubes from the first boiler is exhibited as a specimen, showing the amount of deposit that has been formed during the ten months it has been in use. The deposit is greatest in the lower tubes of the boiler, and decreases in the upper rows: practically it is prevented from accumulating so thick as to cause the tubes to be injured by the heat, since it becomes cracked and loosened from the tubes by their alternate expansion and contraction under the varying temperature of the fire.

At times also nearly all the water is worked out of the tubes so as to let them get quite hot, but not hot enough to cause injury by overheating; and when the deposit is thus loosened in the tubes it is washed out into the receiver by the circulation of the water. The dirt and scale are cleared out of the receiver by a blow-off cock, which is opened for blowing off two or three times a day. It takes about a quarter of a minute to free the blow-off cock from the deposit lodged in the receiver before a full body of water issues from it. Pieces of deposit are blown off which have a circular form, showing that they have been formed in the tubes and then scaled off and washed into the receiver. The semicircular form of the bends uniting the ends of the tubes prevents any incrustation lodging in them by giving an unobstructed passage.

The mode of uniting the tubes together in the former boilers of this construction was with right and left handed screws cut on the ends of the tubes and screwed into the bends: but this make required an entire section of the boiler to be taken out when a new tube had to be put in; and with large boilers this is too much trouble, owing to weight, difficulty of handling, and the impossibility of unscrewing many of the tubes in the bends after they have once been screwed up and put to work. To meet these difficulties a new form of bend has been made in the present boiler, which admits of any one of the tubes in any part of the boiler being taken out, without removing that section of the boiler or interfering with any other joints than those of the tube to be removed. Figs. 4, 5, 8, and 9, Plate 8, show enlarged views of the improved bends. Instead of screwing the ends of the tubes they are made with collars of suitable size welded on, and the ends of the bends are recessed out to receive them: the bends are brought up tight against the collars on the tubes by the centre screw bolt M, Fig. 8, which passes through a hole in the bend in line with the centres of the two tubes, and is screwed into the crossbar N bearing against the outside face of the collars. The passage through the bend is made on one side of the fixing bolt, Fig. 9, to prevent it from obstructing the flow of steam and water. By this plan any of the bends can be taken off through the doorways at the front and back

of the boiler, and any tube can be taken out and replaced. The ends of the tubes are passed through the end bearing plates PP, Figs. 4 and 5, which serve also as shield plates to protect the cast iron bends from the heat of the fire; these plates rest on the walls of the furnace, or are suspended at the top from the girders Q, as in Fig. 2. Figs. 6 and 7, Plate 8, show the mode of joining the tubes to the main supply and delivery pipes, which is done in a similar manner by collars upon the ends of the tubes fitting into recesses in the main pipes and held up tight by a crossbar N and stud bolt. By having valves for cutting off the communication between the receiver and tubes, the steam and water can be retained in the receiver during the time of removing a tube; and when distilled water from a surface condenser is used in the boiler, the water can by this means be saved if a tube should burst, and shut off from the boiler while the repairs are done.

The special advantage of this boiler is that steam of high pressure is generated in it with greater safety than steam of low pressure in ordinary boilers. Its construction ensures almost perfect safety: for the receiver C, Fig. 1, Plate 7, the only portion containing any quantity of steam and water capable of causing damage by explosion, is of the strongest form for resisting pressure, of simple construction, and removed from the action of the fire, so that it is entirely free from the injurious effects of overheating and the alterations of expansion and contraction, which are considered to be the cause of so many injuries and explosions of ordinary boilers. The only portion of the boiler exposed to the fire is the tubes, which are of such small capacity that their explosion is incapable of doing any damage and can only cause the fire to be put out by the water escaping from them. This has been confirmed by the experience with the boiler at the writer's works, where a tube has burst on more than one occasion, whilst the boiler and engine were at work; and the effect was so small that the accident was not immediately perceived, until shown by the loss of steam pressure, the steam and water blowing out upon the fire through the leak in the split tube and putting it out. The advantages of high pressure steam are now generally recognised: but a much higher pressure than can be obtained in ordinary boilers and superheating of the steam are required to develop these advantages fully, by cutting off

the steam earlier with a higher degree of expansion. The economy of expansion is now limited by the weakness of boilers in general use; and a large increase of economy may be obtained if much higher pressures can be safely used.

The leading feature of this boiler is the use of the circulating pump, to maintain a constant and regular circulation of the water through the entire set of tubes forming the heating surface of the boiler. This principle of mechanical circulation is found essential in order to carry out completely the idea of a tubular boiler, in which the heating surface consists entirely of the tubes having the pressure internal, and thereby attaining a maximum of strength and safety with a minimum of material. The rapid generation of steam in the lower portion of such a boiler would so far choke the passage of the tubes as to check the natural circulation of the water and cause the tubes to be rapidly burnt out. The objection arising at first against the adoption of artificial or forced circulation instead of natural,—that it is not self-acting and may therefore be liable to cause interruption to the working of the boiler,—has been satisfactorily proved by the results of the continued working of this boiler to be practically met by the simplicity of construction of the circulating pump, as shown in Fig. 10, Plate 9, previously described. During the ten months that the boiler has been in continual work the circulating pump has always worked well, and never given any trouble except from causes foreign to its principle of working; such as the water freezing in it and breaking it, which occurred once during the late severe frost. In first raising steam in the boiler no difficulty is experienced from the circulating pump not being at work, since the tubes do not require circulation of the water until steam is raised, and the pump then starts with a small pressure of steam, so little power being required to work it.

The portability of this boiler is an important practical advantage for several cases of application. The largest piece, the receiver, is only one tenth the size of an ordinary boiler of the same power; and the tubes can be packed in bundles, giving great advantage for shipping over other boilers both in the reduction of total weight and in the

increased facility for stowage. The economy of space is very great, and an important advantage in many situations where space is limited and valuable; the space occupied being only one sixth to one fourth of that required for ordinary Cornish or cylindrical boilers of the same power.

Owing to the duplication of parts in its construction, the cost of the boiler is but little more than that of ordinary boilers above 25 horse power, including the circulating pump and all the mountings. A small boiler of the kind costs more in proportion than a large one; for in all cases it is best to have an independent circulating pump, and a small pump costs nearly as much as a large one. In this comparison it is supposed that the steam is worked at the ordinary pressures in both cases, say from 25 to 50 lbs. per square inch; but the suitable working pressure for the new boiler is 100 to 150 lbs. per square inch, with the steam superheated and worked expansively; when thus worked and compared with other boilers in first cost per horse power, the new boiler is much cheaper, and in all cases far cheaper for transporting and setting in masonry. The average thickness of the boiler tubes is not more than $\frac{1}{8}$ inch, and their whole surface is effective heating surface; this results in a great saving of weight compared with ordinary boilers with plates $\frac{3}{8}$ to $\frac{1}{2}$ inch thick. In comparison with marine boilers the new boiler can be made much cheaper than those on the ordinary mode of construction, while the facility for repair gives a decided advantage.

Though the steam and water from the tubes are discharged together into the receiver, there is a complete separation of them, and there has not been the least trouble from priming. More fully to prove the fact of their separation, cocks have been placed on the upper and lower sides of the delivery pipe G, Fig. 1, Plate 7, leading from the tubes to the receiver: from the upper cock nothing but steam was found to issue, and from the lower nothing but water; and supposing priming to be caused by taking steam from boilers exposed to the direct action of the fire, it is effectually prevented in this boiler for the reason that no fire acts upon the receiver containing the water, from which the steam is taken off, and consequently the water remains in a quiet state.

Superheating of the steam is effected by returning the steam from the receiver back by the pipe R, Fig. 2, to the upper part of the furnace and passing it through a sufficient number of superheating tubes S, whence it is taken off by the steam pipe T to the engine. The superheating tubes S are arranged and united together in the same manner as the boiler tubes, and are consequently as simple and convenient to get at for erecting and repairing.

The evaporative duty of the boiler with Staffordshire slack has been $5\frac{1}{8}$ lbs. of water per lb. of fuel, without covering the receiver and steam pipes to prevent condensation. Steam has been raised from the time the first shovel of fire was placed in the furnace when cold, without wood or forced draught, to 10 lbs. pressure in 25 minutes, when the steam was sufficient to start the circulating pump; in 10 minutes more there was 35 lbs. pressure of steam, when the engine was started; and in 10 minutes more, being 45 minutes from the time the first shovel of fire was put in the furnace, all the machinery driven by the engine was in operation and there was sufficient steam to produce all the power required. This was with only $\frac{7}{10}$ths of the boiler or 460 square feet of heating surface, $\frac{3}{10}$ths of the boiler being then not at work. The practice at dinner hours and other times when the engine is stopped has been to close the damper, open the firedoors, and cover the fire with ashes and slack, and work the circulating pump as slow as its construction will permit; this entirely prevents generation of steam, and in the meantime saves the tubes from overheating. For starting the engine again, the fire is stirred up and supplied with coals 5 or 10 minutes before steam is wanted, which is ample time to generate a regular and sufficient quantity of steam to commence working all the machinery driven by an engine of 60 horse power. Steam can be regularly maintained in the boiler that has now been in use for ten months, with a variation of from 10 to 15 lbs. pressure when all the work is on the engine with 40 to 55 lbs. steam in the boiler. The pressure cannot be maintained with quite the same regularity in this boiler as in ordinary boilers, on account of the comparatively small amount of steam room; at the same time it is found that a sufficient quantity of steam is made with regularity enough for all practical purposes.

For the purpose of ensuring that the pressure of steam supplied to the engine shall never exceed the intended limit, and of preventing any risk of injury to the engine by over-pressure arising from the comparatively small steam room in the boiler, the regulating valve shown in Fig. 11, Plate 9, has been designed by the writer, and is found to fulfil this object with complete success. It consists of a double-beat valve U, having a piston V below it fixed upon the same spindle and of the same area as the lower valve, and supported by a spiral spring which presses the valves open. The steam from the boiler, passing through both the valve seats, is delivered to the engine by the pipe W; at the same time it acts upon the top of the piston V, compressing the spiral spring below to a greater or less extent according to the pressure of the steam, and thus partially closing the valve and wiredrawing the steam whenever its pressure at entrance approaches the intended limit. The spiral spring is adjusted so as to hold the valve full open until this limit of pressure is nearly reached; but whenever that takes place, the partial closing of the valve checks the supply of steam and prevents the pressure of the steam supplied to the engine from rising above the intended amount. The bottom of the spiral spring is carried by a cylindrical cap X, sliding vertically and supported by the end of the weighted lever Y, which is adjusted to balance the pressure on the piston at the limit of steam pressure. As soon as the intended pressure is exceeded, this lever is depressed immediately, closing the valve entirely and shutting off the supply of steam, thus preventing any increase of pressure in the steam pipe W when the engine is standing, which would otherwise be occasioned by the accumulation of steam gradually passing through the contracted opening of the valve that serves to supply the engine when working. A safety valve Z is added on the top of the casing to make the precaution complete. This regulating valve is in constant work, and maintains the steam supplied to the engine at a uniform pressure. It may also be applied with advantage to low pressure and high pressure engines working in connexion, serving completely to regulate the limit of pressure of the steam supplied to the low pressure engine.

Mr. RUSSELL exhibited specimens of the joints and bends of the boiler tubes, and some of the burst and incrusted tubes that had been taken out of the boiler, as described in the paper. The new boiler had fully answered his expectations since it had been got to work, both in supply of steam and in safety and facility of repairs under any accident that could occur. It occupied only one sixth the space of the two Cornish boilers previously used, and burnt only 3 tons of slack per day against the previous consumption of 5½ tons per day for doing the same work; one engine only was working now, instead of two, and was working up to 60 indicated horse power. The safety of the boiler was a great advantage, and they had had two or three instances of tubes bursting; but no injury was done, and the only effect was that the fire was put out by the steam and water, and the burst tube was replaced by a new one with only two hours' delay.

Mr. J. FENTON observed that the evaporative duty shown by the boiler was low, amounting to only 5½ lbs. of water per lb. of slack.

Mr. RUSSELL said the boiler was at present very unfavourably circumstanced as to evaporative duty, owing to the steam pipes and receiver not being protected in any way; and much heat from the fire was also lost by passing away into the chimney. The advantage to be obtained by the new boiler in economy of fuel would be fully shown when steam of very high pressure was used, which could be safely done only with a boiler upon that construction.

Mr. G. A. EVERITT thought that the consumption of 18 tons of slack per week for an engine of 60 indicated horse power was certainly far from economical; for with Cornish boilers he was burning at his works only 16 tons of slack altogether per week for two engines of 60 nominal horse power, working up to 170 indicated horse power.

Mr. W. RICHARDSON mentioned that in Green's economiser, which he had used for several years past for heating the feed water by the waste heat passing to the chimney, consisting of a stack of upright pipes placed in the chimney flue, through which the feed water was passed on its way to the boiler, cast iron pipes were first used, but they had tried substituting wrought iron pipes, to obtain a thinner metal that would conduct the heat better; these however all became riddled through with small holes in 18 months, by the destructive action of

the condensed water, and had all to be taken out again and replaced by cast iron pipes. The same result had been experienced at several other places where wrought iron pipes had been tried in the economiser; and he feared therefore the wrought iron tubes in the boiler would be destroyed in the same way by their direct exposure to the fire.

Mr. Russell said there had been such long experience of the use of wrought iron tubes in boilers that there was no fear for their durability, and they had been found to last for many years' working with regular circulation through them.

Mr. W. Richardson enquired what degree of superheating was obtained by the superheating tubes in the boiler; he thought this could not be great, as they were placed in the coolest part of the furnace, furthest from the fire. He had tried superheating the steam by tubes placed in the flue beyond the boiler, but found that steam of 70 or 80 lbs. pressure could not be superheated by that arrangement, since the temperature in the flue was scarcely higher than that of the steam itself.

Mr. Russell replied that at 60 or 70 lbs. pressure the steam was superheated about 220° or 240° by passing through the superheating tubes; and after taking out three sections of the boiler tubes the steam was superheated more than 500°, having a temperature of more than 900° after passing through the superheating tubes, in consequence of their having in that case a greater extent of surface exposed direct to the fire, while less of the heat was taken up by the boiler tubes.

Mr. C. W. Siemens observed that the amount of superheating which had been mentioned would go far to explain the low evaporative duty of the boiler; for if the steam were superheated to upwards of 900° by the superheating tubes in their present position close to the chimney, the heat passing away into the chimney must be more than 1000°, which would produce a great loss of fuel. The tubular construction of boiler, in which the entire heating surface consisted of small tubes having great strength to resist internal pressure, was he thought one that might be advantageously employed, and it had been tried in this country by Dr. Alban many years ago, with steam of 150 to 200 lbs. pressure. In the present boiler the circulating pump was the novel feature, producing an artificial circulation of the water

through the tubes; but he questioned the desirability of introducing such a system, on account of the additional complication involved, and thought the plan might be simplified by some alteration in the arrangement, so as to rely on natural circulation alone.

Mr. A. Masselin remarked that the superheating tubes at the top of the boiler next to the chimney were in the least effective position for superheating the steam; and would have been placed with much greater advantage at the bottom of the boiler, immediately over the furnace, if sufficiently durable to stand so close to the fire.

Mr. Benson said the special feature of the boiler was the forced circulation of the water, to prevent the tubes ever being short of water; he was satisfied that a boiler of this construction would not last more than five or six months, were it not for the mechanical circulation, for the tubes would soon tear themselves to pieces by unequal expansion and contraction if exposed to the risk of being alternately full and empty of water, which they would be liable to if dependent on natural circulation. In the case of water heaters that had been referred to, the tubes were soon eaten through by corrosion, and became forced out of position and twisted round, owing to the small quantity of water passing through them; but no such results had been experienced in the tubes of the boilers, because the quantity of water passed through them by the forced circulation was so much greater than that evaporated. The bottom tubes were made 1¼ inch diameter for one third the height of the boiler, then 1½ inch for the next third, and 1¾ inch at the top, which gave an additional security for the bottom tubes being always thoroughly filled with water, while greater freedom of passage was allowed at the top for the mixed water and steam escaping into the receiver.

The chief improvement made since the erection of the first boiler on this construction was the mode of fixing the tubes, in such a manner as to allow of removing and replacing any tube without taking out an entire section of the boiler; a tube could now be taken out and a new one put in in as short a time as 15 to 20 minutes, when the boiler was again ready for work at once.

When the boiler was properly constructed, he had found the evaporative duty was equal to that of any tubular boiler; but in the present

instance the boiler was not working under favourable circumstances for economy of fuel. The sections of the boiler were set 1½ inch apart, and much heat escaped between them direct into the chimney. The draught was also deficient, the chimney being only 2 feet diameter which was too small for the purpose; so that there was not air enough drawn in for thorough combustion of the coal, and smoke generally issued from the chimney for a short time after firing.

The CHAIRMAN asked whether there were any openings for admitting air over the surface of the fire to prevent the smoke.

Mr. BENSON replied that a number of air holes were made in the brickwork on all sides of the furnace, but these were not sufficient to prevent smoke without a greater force of draught.

The CHAIRMAN moved a vote of thanks to Mr. Russell for the paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A METHOD OF SUPPLYING WATER TO LOCOMOTIVE TENDERS WHILST RUNNING.

By Mr. JOHN RAMSBOTTOM, of Crewe.

The object of the apparatus forming the subject of the present paper is to supply Locomotive Tenders with Water without requiring the stoppage of the train for the purpose. It consists of an open trough of water, lying longitudinally between the rails at about the rail level; and a dip-pipe or scoop attached to the bottom of the tender, with its lower end curved forwards and dipping into the water of the trough, so as to scoop up the water and deliver it into the tender tank whilst running along.

The construction of the apparatus is shown in Figs. 1 and 2, Plate 10, which are longitudinal and transverse sections of the tender and water trough. Figs. 3 and 4, Plate 11, are longitudinal and transverse sections enlarged of the scoop and trough.

The water trough A of cast iron, 18 inches wide at top by 6 inches deep, Fig. 4, Plate 11, is laid upon the sleepers between the rails at such a level that when full of water the surface of the water is 2 inches above the level of the rails, as seen in Figs. 1 and 2, Plate 10. The scoop B, for raising the water from the trough, is of brass, with an orifice 10 inches wide by 2 inches high, as shown in Figs. 3 and 4; when lowered for dipping into the trough, its bottom edge is just level with the rails and immersed 2 inches in the water. The water entering the scoop B is forced up the delivery pipe C, Fig. 1, which discharges it into the tender tank, being turned over at the top so as to prevent the water from splashing over. The scoop is carried on a transverse centre bearing D, and when not in use is tilted up by the balance weight E clear of the ground, as shown dotted in Fig. 3; for dipping into the water trough it is depressed by means of the handle F from the footplate, which requires to be held by the engineman as long as the scoop has to be kept down.

The upper end of the scoop B is shaped to the form of a circular arc, Fig. 3, as is also the bottom of the delivery pipe C, so that the scoop forms a continuous prolongation to the pipe when in the position for raising water. The limit to which the scoop is depressed by the handle F is adjusted accurately by the set screws G, which act as a stop and prevent the bottom edge of the scoop being depressed below the fixed working level; the set screws also afford the means of adjusting the scoop to the same level when the brasses and tyres of the tender have become reduced by wear, causing the level of the tender itself to be lowered. The orifice of the scoop is made with its edges bevilled off sharp, to diminish the splashing, and the top edge is carried forward 2 or 3 inches and turned up with the same object.

Two other forms of scoop have been used, but they are not considered so eligible as that already described and shown in Figs. 3 and 4, Plate 11. In one of them the scoop was hinged on the bottom of the delivery pipe C along the front edge, with a set screw as before for adjusting it to the proper level in the trough when the brasses and tyres have become worn. The other form of scoop was made to slide up inside the delivery pipe with a telescope joint; and for adjusting its height the lifting lever was centered in an eccentric bush which could be turned round when necessary, so as to raise the lever and allow for the wear of the brasses and tyres.

The water trough A is cast in lengths of about 6 feet, so as to rest upon each alternate sleeper, and is fixed to the sleepers, the height being adjusted by means of the wood packing, as shown in Figs. 1 and 2, Plate 10. The ends of each length are formed with a shallow groove, in which is inserted a strip of round vulcanised india-rubber H, Fig. 3, to make a flexible and water-tight joint, the metal not being in contact; this meets all the disturbances arising from expansion, settlement of road, and vibration caused by the passage of trains. The length of trough now laid on the Chester and Holyhead Railway near Conway is 441 yards in the level, as shown in the diagram Fig. 5, Plate 12; and at each end the rails are laid at a gradient of 1 in 100 for a further length of 16 yards, the road being raised for that purpose so that the summit of the incline is 6 inches

higher than the level portion: the trough is tapered off in depth to a bare plate, so that the same thickness of wood packing serves for fixing it throughout the entire length. The portion of the line where the trough is fixed is a curve of 1 mile radius, and the outer rail is canted 1 inch above the inner, the wood packing being made taper for fixing the trough horizontal; but the cant does not interfere with the efficient action of the scoop on the tender, since it amounts to only 1-6th inch on the 10 inches width of scoop. At each extremity of the water trough is an overflow pipe I, Fig. 5, limiting the height of water in the trough.

Where the water has to be raised by pumping or the natural supply is limited in amount, it is necessary to prevent the water running to waste through the overflow pipes. For this purpose the supply pipe K, Fig. 6, Plate 12, has a valve L fitted on its orifice, and delivers the water into the small cistern M, from which it flows into the trough A through the pipe N; when the trough is full up to the high water level, the water overflows from the cistern into the pocket O and thence into the bucket P on the end of the valve lever, closing the valve and cutting off the supply water. There is a small hole in the bottom of the bucket P, through which the water in the bucket constantly escapes: so that when the water level in the trough A has been lowered by the passage of an engine, the water in the cistern M no longer overflows into the bucket P, and that in the bucket escapes through the hole at the bottom, allowing the valve lever to be raised by the balance weight at the other end and open the valve for a fresh supply. By this means a large quantity of water is economised, since there is only the small quantity escaping through the hole in the bucket, instead of the water constantly running to waste through the large overflow orifices at the two extremities of the trough.

The trough contains 5 inches depth of water, and the scoop dips 2 inches into the water, leaving a clearance of 3 inches at the bottom of the trough for any deposit of ashes or stones. The trough is so constructed as to present no obstruction to be caught by any loose couplings or drag chains that may be hanging from the trains passing over it; and experiments have been tried with a bunch of

hook chains and screw couplings hanging down behind the tender and dragged along the trough without any damage occurring.

As to any difficulty from ice, a thorough trial has been afforded by the late severe weather. By means of the small ice plough shown in Figs. 7, 8, and 9, Plate 12, which was run through the trough by hand each morning, the coating of ice was removed from the surface of the water, and no more was formed afterwards excepting a film so thin that it was removed by the scoop itself in passing through the trough without being felt at all. It has indeed been shown that the continuance of this action with the succession of trains in ordinary working would be sufficient in this climate to prevent the formation of any ice thicker than could be readily and safely removed by the passage of the scoop alone, even during as severe a season as the last. The present trough, which has been in use nearly three months, is supplied hitherto by a pump, which it may be here mentioned failed once through being frozen up; but a natural stream of water will shortly be connected to it, giving a regular supply by gravitation, and serving to prevent the water freezing by maintaining a constant current through the trough.

The principle of action of this apparatus consists in taking advantage of the height to which water rises in a tube, when a given velocity is imparted to it on entering the bottom of the tube: the converse operation being carried out in this case, the water being stationary and the tube moving through it at the given velocity.

The theoretical height, without allowing for friction &c., is that from which a heavy body has to fall in order to acquire the same velocity as that with which the water enters the tube. Hence, since a velocity of 32 feet per second is acquired by falling through 16 feet, a velocity of 32 feet per second or 22 miles per hour would raise the water 16 feet: and other velocities being proportionate to the square root of the height, a velocity of 30 miles per hour would raise the water 30 feet very nearly (a convenient number for reference), and 15 miles per hour would raise the water 7½ feet; half the velocity giving one quarter the height. In the present apparatus the height that the water is lifted is 7½ feet from the level in the trough to the

top of the delivery pipe in the tender, which requires theoretically a velocity of 15 miles per hour; and this is confirmed by the results of experiments with the apparatus: for at a speed of 15 miles per hour the water is picked up from the trough by the scoop and raised to the top of the delivery pipe, and is maintained at that height whilst running through the trough, without being discharged into the tender.

The theoretical maximum quantity of water that the apparatus is capable of lifting is the cubic content of the channel scooped out of the water by the mouth of the scoop in passing through the entire length of the trough: this measures 10 inches width by 2 inches depth below the surface of the water in the trough, and 441 yards length, amounting to 1148 gallons or 5 tons of water. The maximum result in raising water with the apparatus is found to be at a speed of about 35 miles per hour, when the quantity raised amounts to as much as the above theoretical total: so that in order to allow for the percentage of loss that must unavoidably take place, it is requisite to measure the effective area of the scoop at nearly the outside of the metal, which is ⅛ inch thick and feather-edged outwards, making the orifice slightly bell-mouthed and measuring at the outside 10⅓ inches by 2¼ inches; this gives 1356 gallons for the extreme theoretical quantity.

The result of a series of experiments at different speeds is that

(22 Jan. 1861)	at 15 miles per hour the total delivery is	0	gallons.
,,	22	1060	,,
,,	33	1080	,,
,,	41	1150	,,
(23 Nov. 1860)	50	1070	,,

Hence it appears that the variation in the quantity of water delivered is very slight at any speed above 22 miles per hour, at which nearly the full delivery is obtained; the greater velocity with which the water enters at the higher speeds being counterbalanced by the reduction in the total time of action whilst the scoop is traversing the fixed length of the trough. It also appears that at any speed above that which is sufficient to discharge the water freely from the top of the delivery pipe, all the water displaced by the scoop is practically picked up and delivered into the tender. In these experiments the water

level was maintained the same in the trough each time by keeping it supplied up to the overflow orifice at each end; and the scoop was lowered to the same level each time by means of the set screws, the height of the tender itself being maintained practically the same in each case.

At higher speeds than 22 miles per hour the velocity of the water entering the scoop is much greater than is required to raise it to the height of the tender; and on taking up the water by a prolonged vertical pipe curved forwards at the bottom end, in place of the scoop, it is thrown upwards in a strong jet. By closing the top of this pipe and connecting it to a pressure gauge, it has been found that at a speed of 50 miles per hour the water exerted a pressure in the pipe of 30 lbs. per square inch, maintaining the gauge at this pressure during the passage through the trough. This pressure is equivalent to a column of water 70 feet high, and the velocity due to that height is 46 miles per hour, confirming the actual speed of 50 miles per hour. In order to diminish the velocity at which the water enters the tender tank, the delivery pipe is enlarged continuously from the bottom to the upper end, making the area for discharge 10 times that for entrance, as shown in Fig. 2, Plate 10, so that at 50 miles per hour the water is discharged into the tender at only 5 miles per hour or 7 feet per second, equivalent to falling a height of about 1 foot. The theoretical form for the taper of this pipe for giving a uniform degree of retardation to the current of water throughout its length would be a parabolic curvature hollowed inwards at the sides; but the form considered most eligible in practice is one of uniform taper, to allow more freedom of passage in the middle of its length. The form of the front or convex side of the pipe is however of little moment, as the stream of water flows up the back or concave side without pressing against the convex side, which might indeed be removed in the lower portion of the length, leaving the pipe an open curved trough, without risk of the water escaping.

In the preliminary experiments before constructing the apparatus, a trial was made of the effect of a stream of water issuing through an open trough attached to the end of a large water main, under such a

pressure that a regular stream of water was maintained at a speed of 15 miles per hour. A curved pipe similar in form to the scoop and delivery pipe in the drawings and about 3 feet high was placed in the stream of water facing the current, and the water was found to be raised up the pipe and freely discharged in a stream from the top: the orifice of the pipe was 2 inches by ¼ inch at the bottom and 2 inches by 2 inches at the top, being an increase in area of 8 times. On placing a ⅜ inch pipe bent at the bottom to face the current, the water did not cease to flow over till the top was raised 7½ feet above the level of the stream.

For the purpose of measuring the speed conveniently during some of the experiments, the writer employed the simple instrument shown in Figs. 10 to 13, Plate 13, consisting of a small vertical glass cylinder R half full of oil, made to rotate rapidly on its axis by a cord passed round the trailing axle S of the engine: the depressed centre of the surface of the rotating oil indicated readily and accurately the speed of running by the graduated scale at the side of the glass cylinder.

The principle of action of this plan of raising water for supplying locomotive tenders occurred to the writer several years ago, and he long felt convinced that it admitted of being made practically available for that purpose with some advantages of importance in removing difficulties that are at present experienced under certain circumstances of working the traffic. His attention was forcibly called to this on occasion of having to provide last year for the accelerated working of the Irish mail, which has now to be run through from Chester to Holyhead, a distance of 84¾ miles, without stopping, in 2 hours and 5 minutes. This necessitated an increase in the size of the tender tanks beyond the largest size previously used containing 2000 gallons; or else required the alternative of taking water half way at Conway, either by stopping the train for the purpose, or by picking up the water whilst running. A supply of 2400 gallons is found requisite for this journey in rough weather; and although 1800 to 1900 gallons only are consumed in fair weather, it is necessary to be always provided for the larger supply, on account of the very exposed position of the greater portion of the line, which causes the train to be liable to great

increase of resistance from the high winds frequently encountered. An increase of the tender tanks beyond the present size of 2000 gallons would have involved an objectionable increase of weight in construction, and alteration in the standard sizes of wheels and axles &c. for tenders; and would have also caused a waste of locomotive power in dragging the extra load along the line. By this plan of picking up 1000 gallons of water at the half way point near Conway, where the water trough is fixed, the necessity for a tender larger than the previous size of 1500 gallons is avoided, effecting a reduction in load carried equivalent to another carriage of the train.

Another application contemplated for this apparatus is to the case of heavy through goods trains, such as those between Liverpool and Manchester, which are at present required to stop half way at Parkside for water only, causing an objectionable blocking of a line very much thronged with traffic, and a delay and loss of power in pulling up the heavy train.

Another advantage of this plan is the means it affords of opening up fresh sources of water supply, where a stream of good water can be obtained near the level of the rails without expense and labour of pumping it, but cannot be otherwise made available on account of not being at a station: such as the case of the Holyhead line, where at the terminus on the coast the supply of water is defective in quality and quantity, and involves heavy expense for pumping; but at about 15 miles distance along the line a plentiful natural supply of good water can be obtained at the rail level in the middle of the island of Anglesea, where however the nature of the traffic does not necessitate a stoppage.

Mr. Ramsbottom showed a working model of the apparatus to illustrate the mode of action: and observed that the plan had been matured to meet the special difficulty of working the traffic without any delay for taking in water; it had proved quite successful in practice, and thoroughly accomplished the object intended, and there

was indeed less trouble in taking water with it than with an ordinary water crane. Many plans had been suggested for lowering the scoop into the trough, but none so simple and complete as that adopted of making the line with an incline at each end of the trough; the bottom of the scoop when lowered was level with the rails and quite clear of the ballast, so that it might be lowered a mile before reaching the trough; and it was then gradually dipped down into the water and lifted out again by the incline in the rails at each end, passing 3 inches clear above the ends of the trough. In practice instead of the whole quarter of a mile length of line being lowered 6 inches, only a short double incline was made at each end, rising 6 inches and then falling the same amount towards the end of the trough, the object being to enable the scoop to clear the end of the trough. The velocimeter exhibited was a simple instrument that he had contrived for some previous experiments; it showed the speed correctly by simple inspection, assisting the driver in maintaining a uniform speed in experiments, and was convenient for connexion to the engine.

Mr. C. Markham had had an opportunity of examining the working of the apparatus described in the paper, and could confirm the statements that had been made as to its efficiency. On running an engine through the trough at a speed of about 45 miles per hour, it was ascertained by measurement that more than 1100 gallons of water had been delivered into the tender; and in another experiment the speed of the engine was got up gradually from a state of rest to about 16 miles per hour, at which speed the water began to flow over into the tender freely. He had examined the trough and found it in perfect order, the joints being tight without any leakage. This mode of supplying tenders with water would be of great advantage for long runs, especially where a great speed was required, as it avoided the delay of stopping for water; it would also prove of considerable advantage in the working of through goods trains, by preventing the loss of power in pulling up a heavy train for water only. He doubted however whether there were many railways in this country that would admit of the plan being generally adopted, because it was necessary at each place to have a level of a quarter of a mile long for laying down

the water trough, which could not always be obtained. Where there was a good natural supply of water, the plan appeared a valuable auxiliary means of supplying the tender with water; but he thought it should be regarded as auxiliary, for the engine might be stopped before reaching the trough, at too short a distance to allow of getting up the necessary speed for raising the water, causing detention unless the troughs were numerous along the line.

Mr. RAMSBOTTOM remarked that for picking up water at very low speeds he had proposed placing a flap valve at the bottom of the tender, opening inwards, instead of carrying the delivery pipe up to the top of the tender and turning it over; by this means some height would be saved. At as low a speed however as 22 miles per hour the water was supplied in full quantity to the height of 7½ feet.

Mr. J. E. CLIFT enquired what amount of power was expended in raising the water into the tender whilst running.

Mr. RAMSBOTTOM said the power expended would be little more than the weight of the water lifted to the height through which it was raised, with some addition for friction in the scoop and delivery pipe; there was indeed in this plan a saving of power due to the water having to be raised only to the height of the tender, instead of into a high tank for supplying the water cranes.

The SECRETARY confirmed the statements given in the paper as to the results of working, having been present at the experiments and witnessed the action of the apparatus in work; and the water trough was found to be in complete order after exposure to the long severe frost.

The CHAIRMAN thought the results of the trials were highly satisfactory and showed the success with which the plan had been carried out. He proposed a vote of thanks to Mr. Ramsbottom for his paper, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Fourteenth Anniversary of the Institution.

PROCEEDINGS.

2 May, 1861.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 2nd May, 1861; Alexander B. Cochrane, Esq., Vice-President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Charles Binns, ...	Clay Cross.
Benjamin Dawson, . . .	Ferryhill.
Frederick Thomas Huffam, . .	Bristol.
Sydney Jessop, . . .	Sheffield.
Thomas Jessop, ...	Sheffield.
David Jones, ...	Newport, Mon.
George Low, ...	Kendal.
William Sumner, . . .	Manchester.
Isaac Tipping, ...	Madras.
William Henry Woodhouse, .	London.

The following paper was then read:—

DESCRIPTION OF A SELF-ACTING MACHINE FOR SPOOLING THREAD.

By Mr. WILLIAM WEILD, of Manchester.

Previous to the present century sewing thread was made up for sale in hanks, and it was not till about 1814 that the plan of winding thread on spools or reels, technically called "spooling," was introduced by Mr. James Carlile of Paisley. Thread was first wound upon spools in soft uneven and irregular layers by a common hand wheel, and the top layer was made smooth by the friction of a small piece of calico pressed against it in winding. About 1830 a spooling machine was brought into use by Mr. George Taylor of Paisley, having a single grooved guide for laying the thread upon the spool; this guide was made to traverse longitudinally by two screws geared together, so as to distribute the thread evenly upon the spool, one of the screws acting to regulate the distribution in one direction and the other in the opposite direction. The many-grooved guide and the right-and-left-handed screw were introduced about 1834.

The spools commonly used are made of wood, more or less ornamented; and some also of metal, bone, ivory, and other materials. Wood spools were first turned by hand; but the immense demand for them called attention to the necessity for self-acting machinery for producing them in a rapid manner, and this was invented in 1846 by Mr. John Clark of Glasgow. The wood is first cut into slices having a thickness about equal to the length of the intended spools; from these slices the blocks to form the spools are cut by means of a crown saw, which cuts a piece out of the slice in the form of a cylinder and bores a hole through its axis at the same time. The blocks are next supplied to the self-acting turning machine for turning them to the required shape and length, and are afterwards finished or ornamented by a milling or stamping process. One of the most improved self-

acting machines for turning spools will produce between 70 and 80 gross of spools per day, requiring the attention of one boy at wages of about 7*s*. per week.

For polishing the thread to give it a glossy appearance, it is placed in a solution of starch and then subjected to friction; in the first use of machinery for the purpose the thread was polished in the hank by rotating brushes. This is also done by means of machinery similar to that for sizing warp threads; and the last few layers of the thread wound upon spools for the market are polished in the spooling machine by extra pressure upon the thread guide.

For explaining the construction and action of the self-acting spooling machine forming the subject of the present paper, a slight reference to the process of winding by the hand-spooling machines is requisite. The most improved hand-spooling machines at the present time are placed upon long benches about three feet wide and two feet high, and driven by a shaft passing along under the bench. Each spooling head is driven by a friction clutch or pulley, which is made to engage with the clutch or pulley on the driving shaft by means of a treadle pressed down by the foot of the winder. The spooling head consists of a small headstock carrying a horizontal shaft, from the end of which projects the winding spindle that the spool is placed on. The thread guide is fixed on a sliding rod, and the alternate traversing motion is received from a shaft with a right-and-left-handed screw thread on it; the sliding rod has two arms, each carrying part of a screw nut on opposite sides of the screw shaft, one to gear with the right-handed screw thread and the other with the left-handed, so that by a slight oscillation of the sliding rod first one and then the other nut is thrown in gear with the screw shaft.

In using the spooling head the empty spool is placed upon the winding spindle, and the thread which is drawn from the end of a large bobbin is passed under the thread guide and fixed so as to wind on to the empty spool. The machine is then started, and the winder presses upon the thread guide with the left hand, giving the requisite pressure by the thumb; while the right hand reverses the traversing motion at the end of each layer of thread. When the last layer is

being wound upon the spool, extra pressure is generally given to the thread guide to polish the thread and give it the glossy appearance. When the spool is filled a nick is made in the edge of the spool, and the end of the thread secured in it. The full spool is then removed by means of a lever, as the repeated tight coiling of the thread has compressed the spool tightly upon the spindle. The winders employed in filling the spools are mostly young women, one to each spooling head or spindle.

Attempts have been made to wind thread by self-acting means on to several spools at the same time; but as a large portion of the winder's time is occupied in placing and removing the spools and in fixing the ends of the thread to them, the advantage was found insufficient to induce perseverance for overcoming the difficulties.

The entire operation of spooling thread completely by self-acting means is performed by the machine now about to be described, the invention of the writer; which accomplishes all the process of winding six spools at once, completely by self-acting means. It fixes the empty spools ready for winding, and guides the thread on to them during the winding; and when exactly 200 yards of thread are wound on, cuts a nick in the edge of the spool and draws the end of the thread into it for fastening off; then cuts off the thread and discharges the full spools, and then begins winding again on a fresh lot of empty spools.

The machine is shown in Figs. 1 and 2, Plates 14 and 15. Fig. 1, Plate 14, is a front elevation; the headstock is at the right end, and the machine has six spooling heads, each of which fills one spool at the same time. Fig. 2, Plate 15, is a vertical transverse section through the parts operating upon the spool. Figs. 3 to 7, Plates 16 and 17, show the detail of the winding, thread-fixing, and spool-changing apparatus, drawn half full size.

The thread wound upon the spools is drawn from a large bobbin stuck in the back frame of the machine, as shown in Fig. 2, Plate 15; and is guided and fed regularly upon the spool A by the thread guide B, Figs. 3 and 6, Plates 16 and 17. The spool A is driven at a speed of about 2000 revolutions per minute. The thread guide B

has spring fingers on it, through which the thread is drawn; these clip the thread with a uniform pressure and ensure its being wound with uniform tightness on the spool. The point of the guide where the thread is delivered carries a small swivel piece C on the underside, the face of which is made with fine grooves corresponding to the thickness and roundness of the thread: this grooved piece bears on the thread with a uniform pressure while in the act of being wound; and the swivel joint enables it to coincide correctly with the alternate slight inclination of the thread right and left, since the thread is wound in a right and left handed spiral alternately in the successive layers on the spool. In the ordinary hand-spooling machines the groove in the thread guide has a fixed inclination; consequently, though it smooths the thread in one layer, it slightly cuts it up and roughens it in the next. In winding the last layer of thread, the guide B is prevented from rising by a cam, and thus an extra pressure is put upon the thread which gives it the glossy finish.

The longitudinal traverse of the thread guides B for delivering the thread uniformly over the entire length of the spools is obtained as in the hand machines from a right-and-left-handed traversing screw D, Fig. 1, shown enlarged in Figs. 8 and 9, Plate 18. This screw is held stationary endways in the machine, and driven constantly in one direction while the winding is in progress. The slide rod E carrying the thread guides has two arms, each carrying a segment of a nut, on opposite sides of the traversing screw D, one to gear with the right-handed thread and the other with the left-handed; the alternate vibration of the slide rod E throws one nut into gear and the other out of gear with the traversing screw, and thus reverses the direction of traverse of the thread guides. The power necessary for making the slide rod vibrate the required amount is obtained from two flat springs F, Fig. 9, fixed parallel to the rod, which bear upon opposite sides of an arm G secured on the slide rod E: this arm is made with inclined surfaces for the springs to bear on, as shown in Figs. 10 and 11. As the slide rod traverses towards the right hand, the upper spring becomes bent by being forced up the incline on the top of the arm G, as shown in Fig. 10, while at the same time the lower spring is relaxed by the withdrawal of the incline on the bottom of the arm;

so that at the end of the traverse the upper spring has acquired sufficient preponderance of power to throw the arm over through the required vibration: and in the return traverse towards the left hand, the lower spring is bent back and the upper one relaxed, as shown in Fig. 11, ready for reversing the arm again in the same manner.

The arm G between the two reversing springs is guided by a horizontal plate H, called the shaper plate, shown black in Figs. 8 and 13, Plate 18, against which the extremity of the arm bears. In travelling towards the right, the arm bears on the top of the plate, as shown in Fig. 8, and on arriving at the edge of the plate is thrown down by the force of the top spring; it then travels back towards the left along the underside of the plate, as shown dotted in Fig. 13, and on again arriving at the edge is thrown up by the bottom spring. The shaper plate H is arranged for gradually increasing the length of traverse of the thread guides, as the winding proceeds up the bevil at each end of the spools; the edges of the plate are tapered to correspond with the shape of the bevilled ends of the spools, as shown in the plan, Fig. 9, and the plate is advanced at each double traverse of the thread guides by a ratchet wheel and cam I, Fig. 1; the reversing arm G consequently has to travel each time over a broader part of the plate, making a longer travel before it reaches the edge and reverses the traverse of the thread guides. By changing this shaper plate the machine is readily adjusted to wind any other pattern of spools. When the last layer of thread is being wound on the spools, a projecting stop J, Fig. 8, is pushed forward by the shaper plate H to catch the reversing arm G; and on the arm reaching the edge of the plate it is thrown down through only half the amount of its vibration, so that both of the traversing nuts are out of gear with the screw D, and the traverse of the thread guides consequently ceases. The reversing arm is detained in the half way position by the stop J while the change of spools is effected; but as soon as all is ready for starting again, the stop is drawn back and the arm released, as shown in Fig. 13, throwing one of the traversing nuts into gear with the screw.

When the winding of the last layer of thread is completed, the whole of the winding motion is instantly stopped dead by the appli-

cation of a break K, Fig. 2, Plate 15, consisting of a leather band, shown by the strong black line, passing round a pulley on the main driving shaft of the winding apparatus; the band is suddenly tightened on the pulley by a lever and cam, and holds all the winding motion quite stationary while the operations of fastening the threads and changing the spools are performed. As soon as the winding is stopped, the incision knife L, Figs. 3 and 7, for cutting the nick in the edge of the spool, descends and makes the cut, as shown in Fig. 4, Plate 16, while the point of the spring M fixed on the inner side of the knife presses on the spool close to the last coil of thread, preventing it from uncoiling, and directing the thread into the nick; the thread guide B having previously risen clear of the spool, as shown in Fig. 3. The thread-pushing finger N is then drawn to the right, and pushes the thread past the edge of the spool and round the spring point M, as shown in Fig. 7. The hook O now descends and catches the thread. On the side of the hook next to the spool a knife edge P turned upwards is fixed, against which the hook is pressed by a pinching spring Q on the other side. As the hook descends it first pulls the thread into the nick in the spool, and then draws it past the knife edge, which cuts it off. The loose end of the thread is meanwhile held tight between the hook and the pinching spring Q, as shown in Fig. 5, Plate 16, while the full spool is discharged and replaced by an empty one.

For changing the spools the winding spindle R and back centre S, Fig. 6, Plate 17, are both withdrawn by cams, and the full spool drops into the box below; the cradle T containing the empty spool is now raised by another cam, and the winding spindle R advanced again ready to receive it. The spool is pushed on to the spindle by the return of the back centre S, and is pressed up against a shoulder on the spindle R with driving points inserted in its face for making the spool revolve with the winding spindle. The loose end of the thread, held fast between the hook O and pinching spring Q, as shown in Fig. 5, Plate 16, is in such a position that it gets caught between the spool and the shoulder of the winding spindle, and is thus secured ready for starting the winding.

The thread guides B having left off work on the full spools at the extreme end of their longest traverse have now to be brought back through the length of the bevil end of the spools: this is done by a sliding wedge acting on the end of the slide rod E that carries the thread guides; and the shaper plate H is withdrawn by the same movement. The thread guides are then lowered on to the spools, the break taken off, and the winding apparatus started again, when the winding proceeds as before till the spools are filled. All the movements necessary to make the required changes are produced by the machine itself, by cams arranged for the purpose, without anything being done by hand by the attendant, who has merely to supply the empty spools into the cradles while the winding is going on, renew the large thread bobbins when emptied, and join up any broken thread that may occur.

The three sliding rods U, Figs. 3 and 6, Plates 16 and 17, which give the longitudinal movements to the thread-pushing finger N, the winding spindle R, and the back centre S of each of the six spools in the machine, pass right through the whole length of the machine, as shown by the strong full and dotted lines in Fig. 1, Plate 14, having arms fixed upon them to give the required movements to the several parts. Each arm is fixed upon its own slide rod by a set screw, and has holes in it through which the other two rods slide freely; this avoids having to make the arms cranked to clear the rods, and the rods thus serve the double purpose of communicating the longitudinal movements and of also acting themselves as guides to the arms upon them, thereby giving great steadiness of motion and compactness of construction. Each slide rod is worked by a separate cam, as shown in Fig. 1, the movements of each being entirely independent and distinct from those of the other two.

Of the three driving pulleys V at the right end of the machine, Fig. 1, Plate 14, the outside one drives the whole of the winding apparatus and the screw that gives the traverse to the thread guides; and the inside pulley drives the whole of the change cams which perform the several operations that take place whilst the winding is stopped. The driving belt is traversed backwards and forwards from

one pulley to the other by a cam driven from the middle pulley of the three; this pulley gears with an intermediate shaft, on which is a friction wheel covered with leather, running against another friction wheel on the cam shaft, as shown in Figs. 12 and 13, Plate 18. The intermediate shaft W is kept perpetually running, the driving belt being always partly on the middle pulley; but the friction wheel X on the cam shaft has its circumference notched away at two opposite points, so that it makes only half a revolution at a time and then loses the bite of the friction wheel W. One half revolution of the cam shifts the driving belt from the outside driving pulley to the inside one, and the other half revolution shifts it back again; and the same shaft X carries also the cams that put on the breaks for stopping those parts of the machine that are thrown out of gear by the change of driving belt. An escape plate on the cam shaft has two stops upon it, shown dotted in Figs. 12 and 13, which are caught at each half revolution by a catch on the escape lever Y, so that the cam shaft X is stopped dead the instant that the friction wheels lose their bite. The upper end of the escape lever Y is attached to the shaper plate H that regulates the traverse of the thread guides, whereby the change of belt is made dependent on the completion of the other movements of the machine.

As the cam shaft X, Plate 18, is stopped at the time when the friction wheels have lost their bite of one another, as shown in Fig. 12, it requires a slight turn to start it again till the wheels bite; this is given by the maintaining spring Z, which bears against two studs on the escape plate, and turns the notched wheel X on far enough to enable the leather friction wheel W to bite and perform the half revolution, as shown in Fig. 13. This maintaining spring corresponds to the maintaining spring in a clock, which keeps the clock going during the time of winding up.

The order in which the several operations performed by the machine take place is explained by the diagrams in Plate 19, which show the forms of the changing cams and their relative times of action, and the manner in which the successive movements of the machine are arranged to follow and take up the work one after another,

after the winding of the thread is completed. In these diagrams the path of each cam is delineated on a straight line as a datum line, which may represent the centre line upon which the path of the cam is to be constructed, its length corresponding to the circumference of the cam in that line. The vertical lines are 30 degrees apart, the first and last, marked respectively 0° and 360°, representing the same part of the cam. The circles represent the rollers which the cams act upon, and are all supposed to travel in the direction of the arrow. Fig. 14 represents the cam for lifting the thread guide B, Fig. 3, Plate 16; Fig. 15 represents the thread-fixing and cutting cam; Fig. 16 the cam which makes the incision in the edge of the spool for securing the end of the thread; Fig. 17 the cam which pushes the thread to one side; Fig. 18 the cam which shifts the back centre S; Fig. 19 the cam which shifts the winding spindle R; and Fig. 20 the cam which works the feeding cradle T.

When the filling of the spools is taking place, the driving belt is then working upon the outside and middle driving pulleys V, Fig. 1, driving the whole of the winding and traversing gearing. The thread guides rise as the spools fill, till the last layer but one, when their rise is obstructed by a cam which gives extra pressure to polish the thread; but by the time the last layer is wound on the spool, the cam has turned on far enough to remove the obstruction to the rise of the thread guide. At the same time the escape plate X, Fig. 12, is released, and the belt-changing cam causes the driving-belt to be traversed on to the inside driving pulley, for fastening off the thread and changing the spool; and at the same instant lifts the break off this pulley, and puts on the break K, Fig. 2, to stop the winding apparatus.

At the 5th degree of rotation of the cam shafts the thread guide begins to lift clear of the spool, as shown in the diagram, Fig. 14, Plate 19, and has finished lifting at the 25th degree, and then becomes stationary. The hook for drawing the thread down into the nick on the spool begins to rise at about the 12th degree of rotation, Fig. 15, and has attained the greatest height at the 55th degree, and then remains stationary for a few degrees. The incision knife begins to descend at the 15th degree, Fig. 16, and has made the cut

in the edge of the spool at the 40th degree, and then remains stationary, while the spring point connected with it presses on the spool and prevents the thread from getting unwound. The thread-pushing finger begins its longitudinal movement at the 25th degree, Fig. 17, and ends at the 65th degree, when it has drawn the thread round the spring point and past the end of the spool; the finger then remains stationary, and at this point the hook begins to make the descending movement, Fig. 15, having caught the thread pushed past the edge of the spool by the finger. At the same time that the hook begins to descend, the incision knife begins to rise, Fig. 16, and has risen sufficiently to lift the knife out of the incision at the 85th degree of rotation, when it remains stationary till the 95th degree, to give time for the thread to be drawn into the incision by the descending movement of the hook. The knife then begins to rise again and lift the spring point from off the spool, the ascending movement ending at the 105th degree; and having completed its work it then remains in its original position clear of the spool during the rest of the revolution, as shown in Fig. 6, Plate 17. The finger remains stationary between the 65th and 92nd degrees of rotation, Fig. 17; and having completed its work retires between the 92nd and 145th degrees to its first position.

At the 140th degree of rotation the back centre begins a short backward movement, Fig. 18, which ends at the 150th degree; the object of which is to give clearance so that the full spool may be freely discharged. The winding spindle also begins its movement at the 140th degree, Fig. 19, to withdraw the spindle from the full spool, which is pushed off it by coming against a projection on the bush forming the bearing of the shaft that drives the spindle, as shown at R in Fig. 6, Plate 17. The winding spindle is completely withdrawn at the 195th degree, Fig. 19, and then remains stationary till the 215th degree, when it begins to advance again into its first position, at which it arrives at the 275th degree, and is now again in its winding position, ready to receive the fresh empty spool. At the 185th degree the back centre begins to be withdrawn, Fig. 18, so that the empty spool may be brought into the feeding position, and it is completely withdrawn at the 240th degree, when it becomes stationary.

At this point the feeding cradle containing the empty spool begins to rise, Fig. 20, and has brought the axis of the empty spool opposite to the winding spindle at the 270th degree of rotation, when it becomes stationary. The back centre having remained stationary till the 275th degree, Fig. 18, begins to make the return movement, advancing again into its first position, which it attains at the 325th degree; during this movement it pushes the empty spool from the cradle on to the winding spindle, the thread being caught and pinched between the end of the spool and the shoulder on the winding spindle. The feeding cradle which has been stationary to the 315th degree, Fig. 20, is then lowered again to its first position, at which it arrives at the 345th degree. The hook which has been stationary to the 342nd degree, Fig. 15, holding the end of the thread, begins then to rise to its first position, at which it arrives at the 352nd degree, when the end of the thread is liberated from the pinching spring; and the thread guide which has been stationary to the 325th degree, Fig. 14, begins to lower, the cam ceasing its action at the 355th degree of rotation.

The operations of changing the spools are now entirely completed; and by the time the cam shafts have completed their 360th degree of rotation, a crank upon one of them causes the escape plate X, Fig. 13, to be liberated, and the belt-changing cam immediately turns and traverses the driving belt on to the outside pulley which drives the winding gearing, applying the break to the inner pulley, and taking off that which stops the winding. The filling of the spools then commences, and the same series of operations are repeated for each set of spools filled with thread.

To work these self-acting spooling machines it is important that the spools should be of uniform size and shape. Spools turned by hand would not be sufficiently uniform in this respect; and when this machine was first introduced machine-made spools were not as uniform in size as they have since become. But what is wanted is a uniform standard size and shape for spools: at present each maker has his own size and shape, and they are not constructed according to any definite rule. A uniform standard would be a great advantage in

the self-acting spooling machine, as the same shaper plate could be used for all the spools: the machine however admits of being instantly changed and adapted to any other form of spool, by simply removing the shaper plate and substituting another of the new form. After an examination of a great number of specimens, the best proportions for spools are considered to be the following:—the diameter of the heads equal to three fourths of the length; the diameter of the barrel half the diameter of the heads or three eighths of the length of the spool; the length of the barrel half the length of the spool; and the bevil at each end at an angle of 45 degrees, thus leaving a margin at each end of the spool of one sixteenth of the length of the spool. The angle of 45 degrees is most convenient for the thread guide, and gives sufficient strength in the heads of the spool: where the angle is more acute the heads are thin and the pressure of the thread frequently breaks them off from the barrel. It is also suggested that each size of spool shall be numbered and known by a number, and that this number shall represent the length of the spool in tenths of an inch; so that when the number of a spool is known its size and proportions will be known also.

The diagram Fig. 21, Plate 19, is a scale for constructing the proposed standard spools. The horizontal line is divided by vertical lines at equal distances apart; and at the last vertical line, say the twentieth, intended to represent the largest spool, a point is marked off representing the entire length of the spool or 20 tenths of an inch. This vertical line is then divided into the proportions for the spools as above suggested; and straight lines are drawn from the several points thus obtained to the other end of the horizontal line, whereby the rest of the vertical lines are all divided into similar proportions; and each vertical line being numbered from the small end of the scale will thus have upon it all the dimensions for that number of spool. Upon the diagram, spools are represented constructed according to the scale from the smallest up to the largest size.

The self-acting spooling machine will fill one set of spools in about one minute, placing 200 yards' length upon each spool; occupying

about 54 seconds of that time in winding and about 6 seconds in changing the full spools for empty ones. One machine will fill on an average 18 to 20 gross of spools per day of ten hours, including all stoppages for supplying thread &c. It requires the attention of one person, but there is no skill necessary as in hand-winding; for a person who has never been employed in spooling thread and has never seen a similar machine before will learn all that is required in a few days. With the hand-spooling machines one winder can fill 3 gross of spools per day on an average, placing 200 yards on each spool, at wages of from 6*d.* to 7½*d.* per gross, and can earn from 9*s.* to 10*s.* per week. One self-acting spooling machine of six heads will thus do the work of six hand spoolers; so that, omitting the consideration of skill, five sixths of the labour in spooling sewing thread is economised. And this is not the only advantage, but there is another important saving: of the same quantity of material supplied to hand spoolers and to the self-acting machine, the latter returns 2 per cent. more than the former, showing that more waste is made in hand spooling than by the machine.

In conclusion, to give an idea of the importance of the machine in money value, it may be stated that if generally adopted it will effect a saving in labor and material of £100,000 per annum, the interest of a capital of two millions. The extent and importance of the trade may be judged of from the fact that, according to a moderate estimate, upwards of three thousand persons are employed in the United Kingdom in spooling sewing thread by the hand machines; and they produce between three and four hundred millions of spools per annum, of an average length of 200 yards each, and each thread averaging four single threads.

Mr. Weild showed a working model of the spooling machine, illustrating the successive movements performed in the process of winding the thread and changing the spools; and also specimens of the more important parts of one of the machines. He described the early plans of winding thread in balls, and exhibited at work an

original hand-balling machine constructed by a Frenchman in Manchester about the year 1800 and believed to be the earliest machine for the purpose, and another constructed by Brunel several years later; together with a specimen of one of the present hand-spooling heads.

The CHAIRMAN asked how long the self-acting spooling machines had been at work, and how many of them were in operation.

Mr. WEILD said the first experiments in spooling by a self-acting machine were made about three years ago, and the machine had now been about 18 months at work; there were already about 30 of the machines altogether at work successfully in different parts of the country, principally at Huddersfield, Manchester, Derby, Paisley, and Glasgow. The rate at which the work was done was greatly increased as compared with hand winding, the hand-spooling machines winding only 3 gross of spools each in a day, while the self-acting machine with six heads wound 20 gross per day, and sometimes as many as 22 gross, putting 200 yards of thread on each spool.

The CHAIRMAN enquired what was the cost of the machine.

Mr. WEILD said the cost of a machine with six heads for winding six spools at a time was about £100. The most expensive portions of the machine, the winding and changing gearing and the several cam motions, were just the same whether there were six heads or only one; and therefore a large machine was not much more expensive than a small one.

Mr. J. ANDERSON asked how the length of thread wound on the spools by the self-acting machine was determined, and whether any variation could be made in the length by winding it slacker in some of the layers.

Mr. WEILD replied that the machine was adjusted for any length and form of spool by simply changing the shaper template that regulated the travel of the thread guide; and the number of teeth in the ratchet advancing the shaper template determined the length of thread wound, by fixing the number of layers put on the spool. A slight variation in the tension on the thread in winding would produce a difference of a yard in the length of 200 yards put on the spool; but in the machine the thread was delivered on to the spool through

the spring fingers of the thread guide, the pressure being adjusted by a set screw, which gave it a uniform degree of tension throughout the whole winding. The machine must consequently always put the full length of thread on the spools, and there could be no tampering with it. In hand-winding the thread might be put on carelessly in the inner layers without being even and solid, and then smoothed down in the outside layers by extra pressure with a smoothing pad, so as to look well externally; but in the present machine the winding must be done equally well all through, the whole of the winding being thus equal to the best of the hand-winding. He showed specimens of spools wound by hand-spooling heads and by the self-acting machine; and of winding done by eye alone without a guide for the thread, but simply smoothed over in the last few layers.

The swivelling grooved guide delivering the thread on to the spool was a practical improvement of considerable importance in the self-acting machine; for though only a very slight alteration in the obliquity was required, it was still enough to make the difference between smooth and rough winding; and the machine was nearly being abandoned at first on account of the difficulty of winding the thread with a fixed guide. In hand-winding the obliquity of the guide was altered by a slight twist of the hand to agree with the alternate inclination of the thread, so that the smoothness of the winding was entirely dependent on the skill of the winder; but in the machine the change of direction of the thread itself was sufficient to turn the swivelling guide through the angle required, and the winding was consequently as smooth and good in all the layers as in the last. He showed one of the hobs or dies for cutting the grooves in the thread guides, which were of very fine make and of various sizes, from 180 grooves per inch down to 40, according to the thickness of the thread to be wound; and the grooves were made truly semicircular at the bottom in order to keep the thread round and not flattened by the pressure of an angular groove, as it was considered damaged if flattened.

Mr. J. Anderson enquired what sort of wood was used for making the spools, and whether it was steamed or prepared in any way for cutting them out.

Mr. Weild said the spools were made of ordinary birchwood, which was only dried and cut up by a circular saw into transverse slices like the specimen shown, corresponding to the length of the spools; sometimes it was steamed beforehand, when in a greener state than usual. The demand for spools was so great that it had occasioned a scarcity of birchwood in this country; and a large Paisley manufacturer had imported turned spools from America cheaper than they could be made here, although with the present turning machines a boy at 7*s.* a week could produce 80 gross of spools per day. The slice of birchwood was placed under a machine like an upright drill, having a rapidly revolving crown saw with a drill in the centre, which cut out cylindrical pieces of wood of the size of the spool, with a hole ready bored through the centre. These were put in the hopper of the turning machine by a boy, and fed to a lathe having a set of cutting tools fixed in slides, which came into action successively to turn the sides and ends of the spools; one revolution of a cam then completed the turning of the spools. Some of the turning machines were only partly self-acting, having the cutting tools brought up by a hand lever.

Mr. J. Anderson supposed the spools must be driven very quick for cutting the soft wood smooth without splitting.

Mr. Weild said the speed was so great that, although the wood was cut crossways of the grain, the whole of the cutting was thrown off in a single continuous turning, like a shaving from a plane, down to the very bottom of the spool, instead of in a number of small turnings.

Mr. E. A. Cowper thought the two reversing springs arranged in connexion with the shaper template for reversing the travel of the thread guides formed a particularly ingenious contrivance in the machine: as the tracing finger moved along, it charged one of the springs gradually, whereby it was suddenly thrown down or up at the end of its travel across the shaper template, and it then charged the other spring similarly on its return; the same instrument being thus made to move first up and then down by entirely self-acting means, without any driving motion being communicated to it, except the simple reciprocating horizontal movement received from the traversing screw. He enquired whether the contact shaft at the back of the

machine made any of the changes required in the winding or spool-changing movements.

Mr. Weild said the only purpose of the notched wheel was to shift the driving belt from the outside pulley driving the winding apparatus to the inside pulley driving the change movements, and back again alternately. The arrangement was commonly known as Roberts' contact pulley, originally used in the self-acting mule, for making intermittent movements with alternate intervals of rest.

Mr. F. J. Bramwell observed that neither of the three driving pulleys was really a loose pulley, and since the middle one had the strap always on and was consequently always running, the driving power was always ready for shifting the belt at the instant when required; so that the continuous driving of the machine was kept up without intermission, though each portion of it stood still in turn.

The Secretary had seen the self-acting winding machines at work at Huddersfield, and could confirm the statements as to their satisfactory working: the great speed of winding, and the effective manner in which the winding was suddenly stopped dead when completed, were very striking; and also the steady and gradual action of the succeeding change movements in fastening off and cutting the thread and changing the spools. The working of the machine appeared very perfect and complete, and was stated by the proprietor to be thoroughly successful.

Mr. Weild remarked that one great difficulty that had been experienced at first in getting the machine to work was to stop the winding at the right moment when the spools were full. In winding by hand, the motion being controlled by the winder could be gradually retarded, so as to stop exactly at the end of the last layer of thread; but in the machine the great momentum of the winding parts revolving at such a high speed rendered it impossible to stop at the right point, until the powerful friction break was adopted, consisting of a strap passing round a friction pulley of large diameter. By this means the winding was stopped dead at the proper point, but without any shock, and the gearing and spools were all held quite stationary while the change movements were performed.

The CHAIRMAN moved a vote of thanks to Mr. Weild, which was passed, for his very interesting paper, and the trouble he had taken in preparing the drawings and model by which its ingenious action was exhibited so completely.

The following paper was then read :—

ON A NEW MODE OF COKING IN OVENS, APPLIED TO THE STAFFORDSHIRE SLACK.

By Mr. ALEXANDER B. COCHRANE, of Dudley.

Many varieties of Coke Ovens have from time to time been invented with a view to economise the cost of coking, which have met with variable success; and attempts have recently been made to perfect the adoption of flues underneath the floor of the ovens, which were tried so long ago as 1853 by Mr. Joseph Dunning and have since been attempted frequently but with only partial success. The subject of coking has a most important bearing upon railways especially; and if coke could be obtained at a cost approximating more nearly to the price of large coals than can possibly be the case under the ordinary system of coking whereby little more than a yield of 50 per cent. is obtained, the advisability of again reverting to coke in locomotives instead of coal would be considered, and would probably be judged expedient.

In the ordinary plan of coking, the oven in which the process is performed is a round chamber about 10 feet internal diameter, as shown in Fig. 7, Plate 22, the floor of which slopes gently from the back to the front; the oven is covered in by a dome springing at about 4 feet from the floor and rising to about 8 feet at the highest point. At the centre of the dome the charging orifice is situated, which serves as a chimney in the simplest form of oven, and as the entrance into the general flue of a series of ovens where a separate chimney is employed. The coke is drawn out through the door in front of the oven, and in some instances the coals are also charged through the door. In such an oven, whether it be open-topped, or whether the gases and smoke instead of being allowed to escape immediately into the atmosphere are conveyed along a general flue to a suitable chimney, the process of coking is carried on from the top of

the coals only, travelling downwards until it reaches the floor of the ovens. But the coking could not be carried on without a considerable quantity of air being admitted during a certain period at least of the process; and the fact is that the coking is effected at the expense of the combustion of a certain percentage of the coke which the charge of coals ought to yield. Were not air admitted, the process would stop; and as it is, the ovens are subject to great irregularities from the uncertain draught in variable states of the atmosphere. This is evidenced by the fact that if the draught of an oven is interfered with the oven does not get "burnt off" as it ought to be, requiring perhaps a day longer to be completed or even more; and when the oven is drawn it will be found that the coke is accompanied with the objectionable appearance due to what are called "black ends" or partially coked coals. This great evil has been in a measure corrected by the adoption of a tall chimney to a series of ovens, but in that case arises another objection: in a long series of ovens it is difficult to make the influence of the chimney felt throughout; and consequently of the two systems the original one is still preferred in some instances.

In connecting a chimney to a series of ovens the arrangement found best is to place say 48 ovens in a double row of 24 each, back to back, with a central flue passing between the two rows into a chimney occupying a central position in the block of ovens. But even in such an arrangement, where the farthest oven is separated by only 11 intermediate ovens from the central chimney, it is found impossible to prevent the speedy burning off of the oven nearest the chimney and the tardy burning off of the farthest, the intermediate ovens varying in their regularity according to their distance. It is said the oven nearest the chimney is capable of being burnt off without intentional admission of air, which in the other ovens is usually allowed to enter by only partially closing the door; but the real fact is that the draught of the chimney exercising its greatest force on the nearest oven draws in a quantity of air, imperceptibly though not the less certainly, through the imperfect joints of the temporary door and of the external and internal masonry; and each oven only apparently requires more air as it recedes from the chimney. At the Gloucester railway station the writer believes it was attempted several years

ago to correct this evil by arranging a series of ordinary ovens in a circle around a central chimney, and no doubt the difficulty as regarded the draught was removed; but from some cause or other the whole system is now swept away. Such an arrangement however as that of a central chimney with the ovens arranged in a circle round it would evidently constitute a marked improvement so far as regularity of draught for each oven is concerned; but it is equally clear that with the ordinary construction of ovens as above described much ground would be sacrificed by such a plan.

The yield of ordinary coke ovens rarely exceeds 50 to 52 per cent. of the coal supplied. The experiments which have been made to bring about the adoption of flued ovens have pointed to the importance of making use of the waste heat from the ordinary coke ovens to assist in the process of coking. Indeed all flued ovens have one common object: to make the waste gases circulate in flues either beneath the floor of the oven, where they are ignited by suitable admission of air; or, as in one instance, around the top, sides, and floor of the oven. As may be supposed, the rapidity with which the coking is performed is greatly increased, and the non-admission of air to the contents of the oven is a source of great increase in the yield: but the wear and tear on this class of ovens is excessive. In one instance, where the waste gases are made completely to envelope the oven, the wear and tear amounts to no less than 6*d*. per ton of coke produced; and in a recent plan the writer understands the flues underneath the floors of the ovens are in a very short time so destroyed that the oven must be laid off for repairs, far too frequently to make the plan commercially successful.

The plan of coke oven forming the subject of the present paper, the invention of Mr. Henry Eaton of Bordeaux, is believed to fulfil the requirements of a good coke oven more completely than ovens on the ordinary plan or those having flues underneath the floor. About the middle of last year the writer, having to decide on the class of oven to be adopted at his Tursdale Colliery in the county of Durham, after a careful investigation into the merits of various plans determined to build an experimental block of 12 ovens on Mr. Eaton's plan at

the Woodside Iron Works, Dudley, with the intention not only of testing the value of the ovens for coking North country coal, but also of trying what could be done in coking the intractable slack of the Staffordshire Thick coal, the "fine" of which has hitherto been thrown away as waste in very large quantities. The success was so far complete that it was both decided to adopt this system at the Tursdale Colliery, where two blocks of 12 ovens each are now in operation on this plan and a third in progress: and a second block has also been erected at Woodside, which has been at work for two months.

The new ovens are shown in Plates 20, 21, and 22. Figs. 1 and 2, Plate 20, are a general elevation and plan of a single block of the ovens; Fig. 3, Plate 21, is a sectional plan to a larger scale, and Figs. 4 and 5, Plate 22, are longitudinal and transverse sections of the ovens.

The ovens, twelve in number, are arranged in the form of a circular block, as shown in Figs. 1 and 2, Plate 20, of 44 feet diameter, round a high chimney in the centre, which causes the draught to be equal upon all the ovens, so that the coking proceeds in all alike with equal regularity. Each oven A, Figs. 3 and 4, opens at the back by a flue into the regulator B, from which is a smaller flue leading into the chimney C. At its junction with the oven the size of the flue is about 18 inches square, reduced at the regulator B to 8 inches square, and at the foot of the chimney it is only 6 inches square. The regulator B is a rectangular chamber covered by a moveable plate perforated with holes for the admission of air to the gases disengaged in the process of coking. The square chimney C is divided at the base by diagonal partitions D, Fig. 3, rising a little above the flue levels, the effect of which is to distribute the draught of the chimney uniformly over the twelve ovens in four sets of three each. The flues do not enter the chimney at the same level, but the middle one in each set of three rises above the two on either side, and thus space is economised in the size of the chimney at the base. The top of the chimney is 3 feet square inside, but this is larger than necessary, and it need not exceed 2 feet 7 inches square. The chimney is lined with firebrick for 12 or 15 feet of its height

from the base, to protect the red brickwork from the intensity of the combustion which there takes place. It will thus be seen that the arrangement of a central chimney and its division at bottom by four partitions creates a most uniform draught in each oven of the block, and this uniformity is one of the most important elements to be secured in coking.

The chimney and ovens rest on a foundation E, Fig. 4, Plate 22, made up of cinders and dry rubbish free from any combustible ingredients, well rammed in to secure solidity, over which is laid about 9 inches of concrete. The whole block of ovens is contained by brick walls bound together by bolts and straps, the latter being wrought to the form of the door frames, which are thereby held in their places. Each oven is covered in by an arch, shown in the transverse section Fig. 5, every portion of which is an arc of the same circle. The turning of the arch has been found to be a matter of some difficulty, to ensure permanency; but has been satisfactorily accomplished in the following manner. To make a perfect skewback for this arch, the angle at which the arch beds on the partition walls of the ovens should vary at every point of the walls, on account of their diverging from one another, as they all radiate from the centre of the block. But it has been found best to adopt a medium angle throughout, and cut the last arch bricks on each side of the oven to bed properly to their place. The rest of the arch bricks are all bedded in planes parallel to a centre line through the middle of each oven; so that after starting from the skewbacks, as the lines of bedding planes lengthen and approach the centre, they leave a parallel strip the whole length of the oven and the arch is easily keyed in. This done, the centering being constructed in three convenient parts can be easily taken to pieces and removed through the mouth of the oven.

The charging of the ovens, where one kind of coal alone is used, is done by wagons holding about 10 cwts. of coal each, which run upon a circular railway F, Fig. 4, Plate 22, on the top of the ovens. When the charging is completed, the moveable hopper G is removed, and the hole in the roof of the oven closed by a large slab and luted all round to make it air-tight. Where a mixture of coal is needed it is usually more convenient to fill at the mouth of the ovens. The

plan, Fig. 2, Plate 20, shows half the block of ovens with the railway for charging through the roof of the ovens, and half without the charging orifices in the roof. The progress of the coking can at all times be inspected through a sight hole in the top of the door of each oven, which is closed by a small fireclay plug. When completed the coke is withdrawn very easily from the ovens, as the partition walls are radial and diverging from each other. For watering the coke previous to drawing, a water main H, shown in section in Fig. 4, encircles the block of ovens, having suitable standards fitted with india-rubber hose pipes; at the end of the hose is attached a long gas tube which is put in through the mouth of the oven and moved about to direct the water over the surface of the coke. For facility of handling the tube and working the tools used in drawing the coke, a small portable crane I, Fig. 1, is provided, easily shifted by a couple of men, having a double hook roller, shown in Fig. 6, Plate 22, over which the tools move easily.

The mode of working these ovens is in the first place to dry them off in the usual way, which takes four to six days from the first lighting of the fires. When sufficiently heated, the ovens Nos. 1-4-7-10 are cleared of ashes and charged on the first day, the heat being purposely kept up in the rest of the ovens till they are in their turn charged. On the second day the ovens Nos. 2-5-8-11 are charged, and on the third Nos. 3-6-9-12. By this plan of charging the heat of Nos. 12 and 2 is assisting to impart heat through the partition walls to No. 1 between them; the same takes place with Nos. 4-7-10, each between a pair of warm ovens. For 24 hours therefore Nos. 1-4-7-10 have the advantage of adjacent heat, by which time they have acquired sufficient temperature to permit of the drawing and charging of the one set of adjacent ovens Nos. 2-5-8-11 on the second day without injury. Indeed the first ovens have acquired a sufficient degree of temperature to assist in starting the operation of coking in the ovens charged on the second day. The same remarks apply to the charging of ovens on the third day, those of the first and second day both now assisting to start the coking process in Nos. 3-6-9-12 charged on the third day. For 24 hours the ovens charged on the first and second day are now reacting upon one another, whilst those

charged on the third day are being urged forward to a degree which will enable them on the fourth day to permit of the drawing and recharging of Nos. 1-4-7-10.

In applying the new plan of ovens to the coking of the fine slack of the Staffordshire Thick coal, it is mixed either with bituminous slack from South Wales or with a smaller portion of pitch, in order to impart the necessary caking quality, the want of which has rendered the Staffordshire slack incapable of conversion into coke by any plans previously tried. In either case the requisite binding property is now obtained, and the coke is produced in lumps of large size and excellent quality, and is found of particular value in the blast furnace. With a mixture of 45 per cent. of Staffordshire slack and 55 per cent. of bituminous Welsh slack, the yield regularly obtained in the first block of ovens at Woodside, which is only 42 feet diameter, has amounted to from 55 to 60 per cent. of coke. With a mixture of 75 per cent. of Staffordshire slack and 25 per cent. of pitch, the yield has been from 50 to 53 per cent. of coke. The fluctuations in the yield arise from the variations in the quality of slack obtained from different places, some requiring more bitumen to bind it together. Where the binding is not perfect, considerable waste ensues in drawing the coke. To correct this has been the object of some recent experiments, in which a mixture of 44 per cent. of Staffordshire slack with 44 per cent. of Welsh slack and 12 per cent. of pitch has been used, resulting in a regular yield of from 60 to 65 per cent. of coke. Specimens of coke are exhibited to illustrate the respective binding power of the different mixtures described. The best yields however, as may be supposed, are obtained from coals which contain a sufficient proportion of bitumen to secure binding without admixture: such as the bituminous or caking coals of Durham, Newcastle, and South Wales, from which results of 67½ to 70 per cent. yield of coke are uniformly obtained in these ovens. These results have been obtained from coals supplied from the Brithdir Colliery in South Wales, Pease's West Colliery in Durham, and the Tursdale Colliery in Durham.

In the first block of the new ovens at Woodside, which gave the yields of coke above stated from the Staffordshire slack, the partition walls between the ovens were built 9 inches thick. It is evident however that the thinner the partition walls the more perfect is the communication of heat between the ovens; and the writer found in the erection of the first block of ovens that 9 inches make too thick a wall. The consequence of this mistake was that the quantity of coke produced was not so great as expected, since it was absolutely necessary to assist the progress of the coking by a large admission of air. In France, where Mr. Eaton made his first experiments and where the new ovens have been in operation for several years, the partition walls were about 6½ inches thick. At the Briton Ferry Iron Works in South Wales, where it was decided to adopt this plan of ovens from the success of those at Woodside when they had been at work only a few weeks, the partition walls were built only half a brick or 4½ inches thick, and the results were more satisfactory than any that Mr. Eaton had obtained in France. This was to be attributed solely to the diminished thickness of the partition walls, and led the writer to test the point practically in the first block of ovens erected at Tursdale. In order to make a fair comparison, six ovens of the block were built with 4½ inch partition walls, and six with 9 inch walls. The result was that in the same time 12½ per cent. more coal could be coked in the ovens separated by only 4½ inch walls than in those with 9 inch walls. The thickness of 4½ inches is as little as can be safely used for the partition walls, and it was at first feared they might prove a little weak, being 8½ feet long with an average height of 4½ feet; but bound as they are on all edges they have proved to be thoroughly substantial, and it is intended to adopt this thickness in future. It has already been adopted with perfect safety in the two instances above mentioned, at Briton Ferry and at Tursdale.

The economy secured in the new plan of oven arises from the circumstance that the heat requisite to start and urge the oven forward is supplied chiefly by radiation from the partition walls; and in a few cases only, owing to peculiarity of coal, is it at all necessary to assist the progress of the oven by the admission of air. The

principle of the oven aimed at is the entire exclusion of air, in order to prevent entirely the waste that takes place by partial combustion of the coke in the ordinary process; and this object is attained with certain rich gaseous or bituminous coals. But when dealing with intractable material, air is still needed: from 2 to 3 square inches of air space given beneath the door are amply sufficient to meet the case of the mixture of 45 per cent. of Staffordshire slack and 55 per cent. of Welsh bituminous slack. Whatever air is given to any oven, it is of the greatest importance to introduce it at the commencement of the coking process and not at the end. When introduced during the first period of the operation, its effect is to mix with and burn the gases which are being disengaged in great abundance from the coals, doing the coke very little injury: whilst its introduction towards the end of the operation is productive of serious mischief, for when the gases are beginning to clear off the air is free to attack the surface of the coke, and does so. To this fact there is a remarkable and curious exception in the case of the manufacture of coke from a mixture of Staffordshire slack and pitch, which seems to be accounted for by the formation of a silicious film or crust over the entire surface of the coke, which most effectually shields it from the action of the air. In all cases however, after the gases have ceased to be evolved in quantity sufficient to fill the oven, the further admission of air is prejudicial to the finishing off of the charge, by cooling down both the coke and the oven which contains it. At this period of the operation therefore, as is found the case in the first block of ovens erected at Woodside, it is necessary entirely to exclude the ingress of air, in order to prevent the rapid loss of heat which the oven otherwise sustains. When the air is thus excluded the oven has acquired a sufficient heat to complete the expulsion of all the gases that remain to be evolved, which are seen to issue burning as small jets of flame from the cracks in the mass of the coke. The regulator B, Fig. 4, Plate 22, allows the admission of air beyond the oven through the perforated cast iron plate which covers it, forming a perfect smoke consumer.

The area of the flue opening from the regulator into the chimney is a matter of considerable importance, and admits of an efficient adjustment by simply inserting pieces of firebrick in the passage of the

flue. This is a particular convenience where from any exceptional cause the admission of a considerable quantity of air is needed, as already referred to in the case of the first block of ovens erected at Woodside. Here the simple reduction of the area of the flue from 49 to 30 square inches at its passage out of the regulator occasioned an increased yield of 5 to 6 per cent. of coke. For with the flue full open, the draught of the chimney drew in more air than was required when the greater part of the gas had been driven off, and a surface combustion of the coke ensued with an intense heat, while the yield was sacrificed. It was found impossible to adjust the supply of air so nicely as to prevent waste while the coking proceeded, except by means of reducing the area of the flue, which proved quite efficient. Since in all classes of ovens perfectly air-tight work can scarcely be secured, the regulation of the area of the flue is a matter of importance even where the air is purposely excluded during the coking, in order to prevent its being drawn into the oven through the innumerable small interstices in the brickwork. The prevention of the undue admission of air by this simple expedient was attended with a diminution of the quantity of coal which could be coked in the same time; but this was counterbalanced by the increased yield of coke from the smaller quantity of coal charged. It may be that the checking of the draught has a beneficial influence by causing the gases to lie back a little longer in the oven and there expend a little more of their heat by being more completely consumed. On the other hand it is possible to reduce the flue area too much: for when it was attempted to work with the flue reduced at the passage from the regulator from 49 to about 23 square inches area, the effect ceased to be of any benefit, and on the contrary was slightly injurious in retarding the rapidity of coking and perceptibly lowering the temperature of the oven.

When the coking is completed, the communication between the oven and the chimney is cut off by a damper, consisting of a plain wrought iron plate, which prevents air from being drawn in through the brickwork whilst the coke is lying as it should do from two to four hours after disengagement of gas has to all appearance ceased. The fact is however that a slight disengagement is still though imperceptibly going on, which is made manifest by opening the door of the

oven, when immediately the gas is seen burning at the surface of the coke. It thus gives an improved appearance to the coke to let it lie a little, by getting rid of a tinge of dark colour which exists at the bottom of the coke if drawn too soon after being done.

As regards the general size of the new ovens, it is thought at present that 44 feet external diameter will prove the most convenient, as shown in Figs. 1 and 2, Plate 20 ; though at the Tursdale Colliery the first and second blocks are constructed 48 feet diameter. The objection to the large size is the necessity of providing for a greatly increased expansion of the structure.

As regards the quantity of coke which can be produced from a block of ovens, the second block at Woodside, 44 feet diameter, has turned out about 60 tons of coke per week during the two months that it has been in work. The first block at Woodside, 42 feet diameter, has scarcely turned out 55 tons per week, for the reason already given of too great thickness of the partition walls: whilst the first block at Tursdale, 48 feet diameter, where half the walls are 4½ inches thick and half 9 inches, is capable of turning out 80 tons per week. The block of ovens at Briton Ferry, 44 feet diameter with 4½ inch partition walls, is turning out from 65 to 70 tons of coke per week; and so satisfied are the proprietors that a second block has been erected.

As regards the time occupied in coking, an ordinary oven of 11 feet inside diameter with 95 square feet of floor area will burn off a charge of 5½ to 6 tons of Newcastle or Durham coals in 72 hours. One of the new ovens with 97 square feet of floor area, in the first block at Tursdale 48 feet diameter, with 9 inch partition walls, burns off 4½ tons in 72 hours with only a trifling difference in the gross amount of coke produced. But no account is here taken of the irregularities to which ordinary ovens are subject, and of which some idea may be formed from an incident that took place with the first block of the new ovens at Tursdale. Red bricks having succeeded perfectly in the chimney at Woodside were employed without hesitation in that at Tursdale; but owing to the increased size of the block of ovens, 48 feet diameter instead of 42 feet, and the more intense character of the combustion of the bituminous coals as

compared with the mixture of Staffordshire and Welsh slack, the heat was too great and caused the red brickwork to melt, and ended by closing up every flue. The chimney was then lined with firebricks: but during the time occupied in lining it, the ovens, which were then working in effect as ordinary open-topped ovens, worked most irregularly, never came up to their proper time, and in one instance a three days' charge occupied six days to burn off. It is not meant that ordinary ovens would be frequently subject to such an extreme irregularity as that just mentioned: for in the absence of the central chimney an oven of the new form is ill calculated to create a sufficient draught; whereas in an ordinary dome oven with chimney at top everything is pretty favourable for the admission of the requsite air. Irregularities of one or even two days in ordinary ovens are however of not unfrequent occurrence; and coupled with the accident which led to the necessity of working the new ovens at Tursdale Colliery without the assistance of the central chimney, they show of how great importance the chimney is to secure good and reliable results.

The cost of erection of a block of ovens on the new construction has been as follows at the Woodside Iron Works, the block being 44 feet diameter:—

35,000 Firebricks and clay	112	0	0
27,000 Red bricks and mortar . . .	33	0	0
Cast and wrought ironwork	91	10	0
Tools	8	10	0
Labour in excavation, bricklaying, and concrete, &c.	70	0	0
	£315	0	0

This gives £26 5*s*. as the cost per oven, complete with water fittings, coke benches and tools, but exclusive of any attendant conveniences for keeping the coke in stock. The cost is of course subject to the addition of carriage of materials for erection at any other site, and minor modifications for the variation of circumstances. Where a mixture of coal is not wanted, the ovens can be made with a circular railway so as to be filled from the top, as at Tursdale, the additional expense of which is about £6 per oven.

The cost of working the new ovens where a uniform quality of coal is used is slightly in excess of the working of ordinary ovens in one particular only, that of loading up the coke from the benches into the wagons. In a straight row of ovens nothing is simpler than to run a train of wagons alongside the benches, off which the coke is conveniently filled at one lift. Against this there is the advantage that the labour of cleansing and charging the coal in the case of the new ovens is divided over a larger quantity of coke produced from the same quantity of coal; so that really the difference if any is but slight. The working cost per ton of coke made has been as follows, in the ovens already at work at Tursdale, 48 feet diameter :—

2 men drawing ovens, levelling coals, manufacturing, and keeping coke benches clean, at 3*s*. each per day, (coke made per day 12 tons) . .	6*d*. per ton.
2 boys cleansing coals and charging with tubs, at 2*s*.8*d*. each per day to feed 3 blocks of ovens . . .	1¾
Wheeling and loading coke into wagons	2¾
Interest on outlay, say £450 to cover incidentals, at 5 per cent. . .	1¼
Redemption in say 7 years . .	3½
Wear and tear say	¾
Royalty	3
Total cost of coke exclusive of coals .	1*s*. 7*d*. per ton.

In Staffordshire, with the mixture of slack and the charging done at the mouth of the oven instead of from the top, as might be expected the labour is somewhat greater, while the outlay is about £75 less per block. The cost per ton of coke made in this case is as follows :—

4 men drawing and charging ovens, mixing slack, &c., at 3*s*. 4*d*. each per day, (coke made per day 9 tons)	1*s*. 6*d*. per ton.
Interest on outlay, say £375, at 5 per cent.	1¼
Redemption in say 7 years . .	4
Wear and tear say	¾
Royalty	3
Total cost of coke exclusive of slack &c.	2*s*. 3*d*. per ton.

To the above particulars of cost it is simply necessary to add that of material to arrive at the total cost of the coke manufactured. Taking the value of a North country bituminous slack at 3*s*. 6*d*. per ton, and a yield of 68 per cent. of coke, the cost of coals would be 5*s*. 2*d*. per ton of coke produced. Adding this to 1*s*. 7*d*. the cost of working, the total cost of the coke into wagons would be 6*s*. 9*d*. per ton. It is of course impossible to fix on any uniform price at which to charge the slack: some collieries produce "duff," as the small of the coal is called, in such abundance as to make them glad to have a means of getting rid of it; others set a higher value upon it. Hence it is for each in his particular circumstances to determine how far the adoption of the new system is economical.

It is easier to arrive at the real cost of the coke manufactured in the Staffordshire district, where slack suitable for the purpose can be bought in any quantity at 2*s*. 6*d*. per ton. Assuming this price, the mixture of 45 per cent. of Staffordshire slack at 2*s*. 6*d*. per ton with 55 per cent. of Welsh slack at 12*s*. per ton will cost 7*s*. 9*d*. per ton: and a yield of 57½ per cent. makes the cost of the coke 13*s*. 6*d*. per ton. Adding this to 2*s*. 3*d*. the cost of working, the total cost of the coke amounts to 15*s*. 9*d*. per ton.

The mixture of 44 per cent. of Staffordshire slack at 2*s*. 6*d*. per ton with 44 per cent. of Welsh slack at 12*s*. per ton and 12 per cent. of pitch at 20*s*. per ton costs 8*s*. 9*d*. per ton; which with a yield of 62½ per cent. makes the coke cost 14*s*. per ton. Adding this to 2*s*. 3*d*. the cost of working, the total cost of the coke from this mixture amounts to 16*s*. 3*d*. per ton.

The mixture of 72½ per cent. of Staffordshire slack at 2*s*. 6*d*. per ton with 27½ per cent. of pitch at 20*s*. per ton costs 7*s*. 4*d*. per ton; but the yield in this case is only about 52½ per cent. of coke, owing to the very volatile character of the pitch, and the coke therefore costs 14*s*. per ton. Adding this to 2*s*. 3*d*. the cost of working, the total cost of the coke made from Staffordshire slack with pitch alone amounts to 16*s*. 3*d*. per ton.

As regards the wear and tear on the brickwork of the new ovens, there seems every likelihood that this is very small and unimportant.

A small allowance has however been made in each of the above estimates of the working cost. The first block of ovens erected at Woodside has been in operation since June last year, a period of nearly a year, and does not show the slightest indication of requiring repairs to the brickwork. A little repair has been needed at the door frame castings, owing to the irregular expansion of the casting by heat and its weak form; but the liability to fracture in the faulty plan first adopted has been in a great measure corrected by an amended form of frame.

Among the advantages which attach to the new form of oven is its compactness, which is of importance and is a reason why the oven should be much cheaper in its construction than ordinary round ovens. Taking the case of a double row of ordinary ovens placed back to back, 11 feet internal diameter, the floor area of which would be 95 square feet, with a flue between them common to both leading to a chimney, such a series of 6 ovens in length or 12 ovens in the double row would cover a space of ground $84 \times 28 = 2352$ square feet; whereas the space covered by the largest block of the new ovens yet erected, 48 feet external diameter, is only 1810 square feet, while the floor area of each oven is 100 square feet, the partition walls in this case being 5½ inches thick. Including the coke benches 9 feet wide in the case of the double row of ordinary ovens, the ground occupied would be $84 \times 46 = 3864$ square feet: whilst in the case of the 48 feet block of the new ovens a greater area of ground is covered, taking a square larger by 18 feet than the diameter of the oven, giving $66 \times 66 = 4356$ square feet; with the advantage however of larger stacking room for the coke, for whilst the bench room in the first case cited of 12 ovens in a double row is $84 \times 18 = 1512$ square feet, that of the 48 feet block is 2546 square feet.

In connexion with the subject of rapid coking, a few interesting laboratory experiments have been made at the writer's works. The material operated upon was the coal from the Tursdale Colliery, the composition of which was as follows:—

Carbon	81·46
Hydrogen	7·89
Nitrogen	2·91
Sulphur	1·34
Ash	3·26
Difference (oxygen)	3·14
	100·00

The yield of coke which any coal is capable of producing depends in a certain measure upon its constituents. In general the gaseous products cannot be expelled without carrying off with them a certain proportion of carbon. Could all the hydrogen, nitrogen, sulphur, and oxygen be expelled without carbon, the coal of which the above is an analysis should yield nearly 85 per cent. of coke: but the highest result obtained in the laboratory was only 69¼ per cent. The yield of coke however is dependent also to a certain extent upon the rapidity with which the coal is raised to the coking temperature, as the following five experiments will show.

In the first experiment two crucibles carefully covered, containing Tursdale coal, were introduced into a close muffle, so that access of air to the contents of the crucible was rendered impossible. The muffle was at a very bright red heat, and the crucible having been put into it the mouth of the muffle was temporarily stopped. In one hour afterwards the crucible was removed, and the percentage of coke in one crucible was 62·18 and in the other 61·28.

In the second experiment a crucible was introduced into the muffle when cold, and the temperature gradually raised during one hour to cherry red, and then maintained for half an hour at a bright red heat. The yield in this case was 66·12 per cent. of coke.

In the third experiment two crucibles were introduced into the muffle when at a bright red heat, but not so hot as in the first experiment, and the temperature was maintained for an hour. One crucible gave 64·77 per cent. of coke and the other 64·20 per cent.

In the fourth experiment a crucible as in the second experiment was introduced into the cold muffle, and the temperature raised in an hour and a half to cherry red, instead of occupying only one hour as in the former case. The resulting yield was 67·50 per cent. of coke.

In the fifth experiment a crucible introduced into the muffle at a dull cherry red heat and kept at that temperature for one hour yielded 69·40 per cent. of coke. A second crucible raised in one hour to a dull cherry red heat and kept at that heat for one hour also yielded 69·40 per cent. of coke.

It appears from these experiments that the more rapidly the coal is coked or the higher the temperature of the oven into which it is introduced, the less the yield; and this is no doubt due to the greater readiness with which compounds of carbon and hydrogen containing an increasing proportion of carbon are formed, the more sudden or the greater the intensity the heat. On the other hand it was noticed in the above experiments that the coke more slowly made was more bulky, that is less dense, than that made more rapidly. This result fully accords with that obtained in some flued ovens in the north, the invention of Messrs. Breckon and Dixon; the coke produced by the flued ovens being much denser in character than that made in ordinary ovens. How far yield is interfered with by the use of flues is a question which admits of further enquiry; and at some future time the writer may be in a position to make a comparison between Tursdale coke produced in flued and non-flued ovens in order to determine this point. Taking an average however of several specimens of coke produced in ordinary ovens from North country coal, the specific gravity is only 1·00, whilst the specific gravity of Tursdale coke made in the new ovens is 1·47. However much therefore this high specific gravity of the coke may be due to some favourable peculiarity of the coal, it is evident that in the new mode of coking both yield and density are secured. There is a further objection to coking from the bottom of an oven upwards, as in ovens having flues underneath the floor, from the fact that the two processes meet in an irregular plane about one third of the way up from the floor of the oven, and there result two measures, so to speak, of coke. This is perhaps a trivial objection, inasmuch as it interferes only with the commercial appearance of the coke and is no real detriment to its quality; still it is one which is obviated in the new ovens.

The CHAIRMAN exhibited specimens of the coke made in the ovens, illustrating the respective binding properties of the different mixtures of slack employed. He observed that the main object of the plan of coking now described was to effect economy of material in ironworks by making use of the great quantity of fine slack that was at present thrown away as waste; which was of particular importance in the South Staffordshire district, where they were gradually getting short of material by the rapid consumption of the Thick coal within the limits at present worked. Attempts had previously been made to coke the fine slack by itself, but had quite failed; and he had then tried it mixed with Welsh bituminous slack, to impart the requisite binding property, and with pitch. By this means the refuse ordinarily thrown away was converted into a coke even superior to the best coke made from the large Thick coal, the proportion of pitch mixed with the slack being about 27½ per cent. of pitch to 72½ of slack. The coke obtained had all the excellent qualities of the Thick coal coke, and the same freedom from injurious ingredients, since the pitch imparted no noxious elements. In bringing the subject forward for discussion his object was to show the practicability of the plan by the results already obtained; and also to ascertain how far the same process was capable of being extended to other non-caking coals, and whether the new form of ovens was suitable for other districts, as had already been found to be the case in the trial of the ovens at Tursdale with North country coals and at Briton Ferry with South Wales small coals. He was indebted to his son for carrying out the several experiments that had been made with different mixtures of slack.

Mr. W. HADEN quite agreed with the importance of the subject; for if they were enabled to make a really good and regular coke from the waste slack of South Staffordshire it would be a great gain to the district. He enquired what was the effect of using a smaller proportion of pitch with the slack.

The CHAIRMAN said with a smaller proportion of pitch the mixture was not sufficiently binding, so that the coke produced would not hold together, but came out of the oven all in small pieces.

Mr. N. N. SOLLY enquired whether any trial had been made of New Mine slack for coking; and whether the Thick coal slack had been tried by itself since the new ovens were got to work.

The Chairman had not yet tried New Mine slack, and the Thick coal slack would not bind at all by itself.

Mr. N. N. Solly asked whether the flues from the ovens to the chimney had ever got choked up with any accumulation of dust, in consequence of using entirely the fine slack for coking.

The Chairman said there was not the least accumulation in the flues, the draught on the ovens being so strong as to carry off any fine particles of slack.

Mr. Samuel Lloyd suggested that a saving might be made by placing a vertical boiler in the centre of the block of ovens, where the chimney at present stood, so as to economise the heat passing off from the ovens. He thought the heat would be found considerable from so many ovens, as four moderate sized coke ovens at their works at Wednesbury gave heat enough to raise the steam of a boiler 28 feet long and 8 feet diameter. The chimney might be placed in any convenient position near, with an underground flue to it from the ovens.

The Chairman replied that in this instance the boilers were too far off from the ovens to make that practicable; and it would be a question whether it was really advisable to encumber the ovens with a boiler, as there did not appear to be gas enough escaping from the chimney to be worth the trouble of saving.

Mr. E. A. Cowper asked what sort of coke was made in the ovens referred to at Wednesbury, whether as large and dense as that shown from the new ovens; for if there were gas constantly burning out of the chimney there must be a waste of material in the oven and a smaller yield of coke.

Mr. S. Lloyd replied that the coke made at those ovens was only a light soft coke.

The Chairman remarked that the new ovens had an important advantage in the greatly increased density of the coke produced, which had a great deal to do with its quality as fuel and its value in the blast furnace: with the mixture of fine slack and pitch, the specific gravity of the coke produced was as much as 1·25 or 1·30; and the Tursdale coke made in the new ovens had a specific gravity of 1·47, while that of the best North country coke scarcely reached 1·00 in

the regular make. This showed clearly the importance of preventing the waste of so much valuable material out of the coke, which at present took place with ordinary ovens. The specific gravity was ascertained by weighing the coke solid in air and in water.

Mr. J. E. Swindell asked what was the value in the blast furnace of the coke made by the new method, as compared with the best North of England coke.

The Chairman replied that there was no question as to the superiority of the Staffordshire slack; it made a better and purer coke than the North country coals, whether coked with pitch alone or with a mixture of Welsh slack and pitch. With Durham coke they were not able to make a good open-faced grey forge pig, but with this coke good grey pig was regularly made. It also gave a better yield in the furnace than either the Durham coke or that made from the Thick coal.

Mr. S. Lloyd supposed the coke would be more free from sulphur than the North country cokes.

The Chairman said that was the case, the slack being like the Thick coal itself for purity of quality.

Mr. E. A. Cowper asked whether any means were taken to rid the slack of iron pyrites by having it picked before being put into the ovens.

The Chairman replied that the slack was not picked or cleaned in any way before coking, but was put in the ovens just as it was thrown over the bank; the fine slack that he was using was the refuse left after the coarse slack had been screened for making what was called breeze to be used under boilers and for other purposes. In this way 60 tons of good coke per week were now being produced from refuse coal slack previously of no value whatever.

Mr. W. Haden had no doubt many colliery owners would be glad to supply any quantity of the refuse slack for coking, merely for the sake of getting rid of it out of the way.

Mr. J. Murphy enquired whether the mixture of Welsh slack or pitch alone produced the cheapest coke.

Mr. C. Cochrane replied that the coke made with pitch alone was decidedly the cheapest at their works at Dudley, about 1*s*. per ton

cheaper than with Welsh slack, on account of the price of the Welsh slack and the cost of conveyance from such a distance. The cost of the two modes of coking in any locality depended of course on the relative cost of the materials for mixing; and the estimated cost given in the paper was of a general character, based upon the full market value of the pitch and Staffordshire slack, which however had been obtained at a lower rate in this particular instance at their works at Dudley.

Mr. J. Murphy enquired which coke was best for ironmaking.

Mr. C. Cochrane replied that the mixture with pitch alone gave the coke that made the best iron; with this coke grey forge pig iron could be produced with great facility, as the sulphur contained in the coke was not more than 0·8 per cent., whilst that quality of iron could not be made with Durham cokes at all.

Mr. J. Paddon observed that the economy and advantage of any mode of coking would vary much in different localities, according to the quality and cost of materials in the district. In Staffordshire it was a great object to economise the waste slack now thrown away as useless; and the plan of coking just described converted into a valuable fuel what was otherwise worthless. In some parts of South Wales also there was material which had never before been converted into coke, such as the Aberdare slack and other small coals, and this was now coked in the new ovens by mixing with it a portion of bituminous slack. In other parts of South Wales however the case was not the same, the cost of slack being not more than 2*s.* or 3*s.* per ton less than that of the whole coal: where the slack was bituminous it made good coke by itself without any mixture, and anthracite slack was mixed with half as much of the bituminous slack, producing one of the best blast-furnace cokes in South Wales, which cost only 8*s.* 6*d.* or 9*s.* per ton.

The value of the new ovens he thought had been rather understated in the paper than the contrary, the coke having been weighed dry immediately on being drawn; but if stacked and left exposed to the atmosphere for some time, as was usually the case, it absorbed a considerable proportion of moisture which increased the apparent weight; and in estimating the commercial value of the coke as

compared with that made in the ordinary ovens, both should be weighed under the same conditions. Even without this precaution however the new ovens appeared decidedly superior in yield; he was satisfied they would yield in regular work as much as 70 to 75 per cent. of the coal used, and knew of one instance in which the yield reached 78 per cent., when the coke would have weighed still more if it had been left stacked after drawing. As regarded the duty of the coke in the blast furnace, he had seen the new ovens working at the Briton Ferry Iron Works, and was informed by the furnace manager that the coke from the new ovens did fully 7 per cent. more duty and was a finer coke than any made from the same coal in ordinary ovens.

The new ovens had therefore a superiority not only in the greater yield and density of the coke produced, but also in giving the means of making a commercially valuable coke from a material never before successfully employed for any useful purpose; and he was sure the economical using up of the vast quantities of waste slack at present thrown away was a most important problem for the future prosperity of the South Staffordshire district.

Mr. J. Anderson moved a vote of thanks to the Chairman for his very interesting and valuable paper, which was passed.

The following paper, communicated through Mr. Walter May of Birmingham, was then read:—

ON A BOILER, ENGINE, AND SURFACE CONDENSER, FOR VERY HIGH PRESSURE STEAM WITH GREAT EXPANSION.

By ALEXANDER W. WILLIAMSON, Ph. D., and Mr. LOFTUS PERKINS, of London.

The Boiler, Engine, and Surface Condenser, forming the subject of the present paper, have been designed, constructed, and worked by the authors with a view to promoting the adoption of very high pressure steam with great expansion: the engine is of 60 horse power and works at a pressure of 500 lbs. per square inch, as it was thought desirable to adopt at once appliances suited for considerably higher pressures than those proposed for general use. Although however it has been endeavoured to make a boiler which would be safe at any attainable steam pressure, it is not considered necessary by the authors for the present requirements of steam engines to use pressures above 140 to 160 lbs. per square inch: and the practical object of the present paper is to give substantial grounds for confidence in working at such moderate pressures; and to show how, with steam at these moderate pressures, engines free from the most serious drawbacks of ordinary expansive engines can be made to work with a consumption of 1 to 1¼ lbs. of coal per horse power per hour. As the use of impure fresh water or of salt water is attended with a variety of inconveniences and disadvantages, which are more serious the higher the pressure that the boiler is worked at, it appears indispensable to use a surface condenser for an engine working at high pressure; so as to condense in a pure state all the steam that goes out of the boiler, and supply nothing but distilled water by the feed pump: and several important incidental advantages are gained by this plan.

The Boiler, shown in Figs. 1 and 2, Plate 28, consists of a number of horizontal straight wrought iron tubes A, welded up at the ends, and connected with one another by smaller vertical pipes B, as shown enlarged to one quarter full size in Fig. 6, Plate 25. These tubes contain the water to be evaporated, and the steam, whilst the fire is outside them. It is essential that the larger tubes be horizontal or nearly so, and that each of them be connected to the next tube by means of two of the connecting pipes. The boiler contains five layers of the larger tubes of 2½ inches internal diameter and 3 inches external; the connecting pipes are ⅞ inch internal diameter and 1⅜ inch external. In working, the water level is in the middle layer of tubes, as shown by the dotted line in Figs. 1 and 2; it remains free from the violent undulations which occur frequently in boilers where the internal space is not divided off. It is probable that a circulation establishes itself in the water, which rises with the bubbles of steam through the vertical connecting pipe at one end of the tube and descends by itself through that at the other. The hot gases from the fire pass backwards and forwards between the layers of tubes, as shown by the arrows in Fig. 2, and remain long enough in contact with them to allow of a very good absorption of the heat. In another similar boiler used for some time there were eight layers of tubes above the fire. The boiler is thus made up of a number of vertical subdivisions arranged side by side, each containing five to eight parallel tubes. The several sections are all connected together at the bottom by means of a cross tube C with connecting pipes to each section, through which the water finds the same level in all the sections. The steam is taken off through a similar cross tube D at the top of the boiler, with a connecting pipe to the highest tube of each section. All the sections are proved with water pressure up to 3000 lbs. per square inch.

The boiler has about 12 square feet of grate surface, but the total area of the air spaces between the bars does not amount to more than is supplied by 6 square feet of ordinary grate surface; and accordingly the fire is large but slack. The total heating surface amounts to 882 square feet. The capacity is about 40 cubic feet, half of which is water space and half steam room. The whole boiler is firmly held together by cast iron girders, and encased in non-conducting sides and

top made of four thicknesses of light plate rivetted together and kept about ¾ inch apart by ferrules, so as to form three closed air chambers. This arrangement is specially adapted for marine boilers.

The flue from the boiler is made to pass through a box E, Figs. 3 and 4, Plate 24, containing the three cylinders of the engine, passing first down the small or high pressure cylinder F, then up the middle one G, and finally acting on the low pressure cylinder H. The temperature of the gases in this box varies from 400° to 500° Fahr. After leaving the box they pass downwards through a vertical square flue 10 feet long, giving up their remaining heat to the feed water which is forced up through a wrought iron coil of ⅞ inch pipe contained in the flue, having 200 square feet of heating surface. At the bottom of this flue the gases enter a vertical iron funnel of 40 feet height and 24 inches diameter. The heat is so completely abstracted by the feed-water coil that after leaving it the gases have never been found hotter than 100° Fahr.

This small quantity of heat in the chimney gave sufficient draught to cause the evaporation of 8½ cubic feet of water per hour in the boiler; but by the aid of a small fan, driven by a belt from the main shaft of the engine, the evaporation was usually kept at 15 cubic feet per hour. The evaporating power of the boiler was tested by means of a water meter, and in an experiment of 5 hours' duration 390 lbs. of anthracite coal evaporated 420 gallons of water, which is about 10¾ lbs. of water per lb. of coal. There is no doubt that a larger boiler with smaller proportionate loss of heat by radiation to the outer air would give a still more favourable result.

The great strength of this construction of boiler is the result of its being in reality an aggregate of a number of very small boilers. It absorbs the heat from the fire with the facility of a moderate thickness of iron, ⅜ inch, without ever having a calcareous lining to keep the water away from the hot metal; while at high pressures it is exposed to less strain than ordinary boilers at comparatively low pressures. Thus the shell of a cylindrical boiler of 5 feet diameter, or 26 times the internal diameter of these tubes, will be exposed to 26 times as great a strain as the sides of the tubes when containing steam of the same pressure; or at 19 lbs. pressure it will have as

great a strain as the tubes at 500 lbs. But even if tubular boilers were made so thin as to be equally liable to give way with large boilers, they would still be much safer to use; for if one of the tubes were to be destroyed, the water from the neighbouring tubes would be driven out through the small connecting pipes, by which it is in communication with the rest of the boiler, in a very quiet sort of way compared with that in which the contents of a large boiler are thrown out when one of its ends gives way or its shell is rent open. In fact explosions in the ordinary sense of the word are impossible with these tubular boilers. It is well known that tubes are more effective and safe when containing the water and steam within them than when containing the hot gases from the furnace and exposed to an external pressure of the surrounding steam, since the tenacity of wrought iron is greater than its stiffness. The tubular boilers also admit of being easily and speedily repaired, by taking out a defective section and replacing it by a fresh section or by new tubes kept in store for such contingencies. So little space is taken up by the tubes of these boilers that more space can be afforded for the flues and firegrate surface than usual; and the whole space occupied is only about half that taken up by plate boilers of equal mechanical power.

The Engine, shown in Figs. 3 and 4, Plate 24, is of 60 horse power and works at a pressure of 500 lbs. per square inch. It consists of three single-acting cylinders of 12 inches stroke, all attached to a single crosshead I with a connecting rod at each end to the crank shaft K. The steam passes through the three cylinders successively, the down stroke being made by the simultaneous action of the first and third cylinders F and H, and the up stroke by the action of the middle cylinder G alone; so that the three attached to the same crosshead act as regards the rotation of the shaft like one cylinder.

The diagram Fig. 7, Plate 25, is a vertical section of the three cylinders to a larger scale, showing the position of the valves during the up stroke. The steam after having expanded in the down stroke above the piston of the first cylinder F of 6 inches diameter is allowed by the lifting of the conical valve M to pass under the piston of the

second cylinder G of 15 inches diameter, and at the same time under the piston of the first; so that during the up stroke or working stroke of the second piston, the piston of the first cylinder is in equilibrium, and the steam is expanding into the second cylinder of 6 times the area. The valve M between these cylinders then closes, leaving open the passage between the bottoms of both, while the first cylinder F is receiving a fresh supply of steam from the boiler through the steam valve L. At the same time the valve N between the second and third cylinders G and H is lifted and the steam allowed to pass above the pistons of both these cylinders, leaving the second piston in equilibrium and driving the third piston down. In the down stroke therefore there is the same pressure of steam in the top of the third cylinder H, in both ends of the second cylinder G, and in the bottom of the first cylinder F. The bottom of the third cylinder is constantly in communication with the vacuum of the condenser. The third cylinder is of the same diameter as the second, so that at the end of the down stroke the steam has expanded to about 12 times the volume of the first cylinder. When the down stroke is completed, the conical exhaust valve O allows the steam from the top of the third cylinder and also from the top of the second to escape into the surface condenser P, Fig. 3, Plate 24; whilst the valve N between the second and third cylinders falls to its seat, closing the passage between the bottom of the second and the tops of both. The whole effect therefore of this arrangement, which works with great simplicity, is that in the up stroke the first and third pistons are in equilibrium and the second piston has the vacuum on the top of it; and in the down stroke the second piston is in equilibrium and the first piston works against a back pressure equal to the pressure of the steam on the top of the third piston.

The indicator diagrams from the three cylinders are shown in Figs. 8 and 9, Plate 26. That from the first cylinder, Fig. 8, was taken from the passage between the first and second cylinders at the point R, Fig. 7, since there was not room for fixing the indicator on the small cover of the first cylinder. The cylinders being all single-acting, with the pistons in equilibrium during the return stroke, the exhaust line in each diagram represents the back pressure on the

opposite side of the piston during the working stroke: so that each diagram represents completely the effective pressure in each cylinder, as in diagrams taken from ordinary double-acting cylinders. In Fig. 8 the back pressure on the bottom of the first piston during the down stroke is the same as the working pressure on the top of the third, as already explained, while the bottom of the third cylinder is open to the condenser; and in Fig. 9 the up stroke of the second cylinder is made against the vacuum of the condenser.

When the steam in the first cylinder is allowed to expand to 4 times its original volume during the down stroke, it has expanded to 7 times as much or 28 times its original volume by the end of the up stroke of the second cylinder; and hence a considerable fall of temperature necessarily takes place in the steam, with a consequent abstraction of heat from the inside of the first cylinder, and also from the bottom of the second, which is still further cooled by the expansion of the steam in the third cylinder to 48 times its original volume. Not only are the two last cylinders cooled by contact with steam which has lost heat by great expansion and is reduced to a temperature considerably lower than that at which it entered the first cylinder; but still more by the evaporation at low pressures of the water deposited at the beginning of the stroke by the condensation of steam upon the cooled sides of the cylinders. That water is contained in the bottom of the second cylinder was proved by inserting a screw cock at the lowest part of the passage between the second and third cylinders; and another proof is given by the remarkable fact that the quantity of steam calculated from the end of the indicator diagram of each successive cylinder is $6\frac{2}{3}$ cubic feet from the first, $9\frac{1}{3}$ cubic feet from the second, and nearly 14 cubic feet from the third, showing that steam is condensed at the beginning of the stroke of the first and second cylinders, and subsequently evaporates into the next cylinder. The first and second cylinders together condense about half the steam, a proportion which probably does not exceed the condensation of many condensing engines of far less expansion; yet on account of the higher initial pressure of steam the consumption of coal per horse power is only about $1\frac{1}{2}$ lbs. per hour.

The engine was made to run fast in order to allow little time for evaporation of internal moisture in the cylinders between the strokes; and in all respects gives the most favourable trial to the principle of great expansion from a high pressure through a succession of cylinders communicating directly with each other. In order to preserve from injury the cotton packing of the rod that lifts the steam valve L, Fig. 7, of the first cylinder, which is exposed to steam of very high temperature, a horizontal cast iron tube about 18 inches long is fixed to the valve chest above the cylinder, containing a steel shaft with a cam on its inner end which lifts the valve. The shaft nearly fills the cast iron tube, and all escape of steam is prevented by a stuffing box packed with cotton at the outer end of the tube, which always remains cold since there is no passage of steam through the tube. This plan of lifting the valve is found perfectly effective and convenient.

For constructing larger engines to expand a greater number of times effectively, the arrangement that is most advantageous depends upon the initial pressure of steam. If steam is used at 500 lbs. initial pressure, it is thought best first to expand it down to about 125 lbs. pressure in a couple of single-acting cylinders, connected either on opposite cranks or at opposite ends of a lever, so as to be equivalent in their action to one double-acting cylinder. The valves would be conical valves lifted in the manner described above. From 125 lbs. the steam may then be expanded down further through a succession of double-acting cylinders with ordinary slide valves.

But for most purposes there is no doubt that sufficient economy of fuel can be attained by working at an initial pressure of 160 lbs., and by expanding the steam about 16 times, if it be done properly; and the appliances for this purpose are of the simplest kind, involving no novelty of construction but merely of arrangement. It is submitted that the mechanical and physical defects of all existing arrangements for getting more work than usual out of steam, by making it expand many times in one cylinder, may be avoided and their object more fully carried out by four common double-acting cylinders with simple slide valves. The cylinders would be of the same stroke, with areas

in the proportion of 1, 2, 4, and 8, connected to four cranks on the same shaft, and with moderate sized tubular steam chambers to dry and slightly superheat the steam between each cylinder. By making the first and second cylinders work on opposite cranks and close to each other, one would be pulling up while the other is pushing down, thus neutralising the friction on the main journals. The third and fourth cylinders would likewise work on opposite cranks, set at right angles to the first pair, so as to distribute the power with uniformity throughout the whole revolution, the steam being cut off in each cylinder at two thirds of the stroke. Each cylinder communicates with the next by means of a steam chamber composed of drawn tubes connected together in the same manner as the tubes in the boiler already described, and placed in the flue from the boiler for the purpose of superheating the steam to maintain the initial temperature throughout the whole expansion. Each steam chamber supplies steam to the next cylinder during the first part of the stroke, until the slide valve cuts it off and allows the steam to expand during the remainder of the stroke; and in each stroke as much steam is supplied to the chamber from the preceding cylinder as goes out into the next cylinder. Thus the supply of steam to the second cylinder being cut off at two thirds of its stroke, which is also two thirds of the exhaust stroke of the first cylinder, the remaining steam in the first cylinder and the intervening chamber is compressed into the chamber during the remaining third of the stroke, its pressure being thereby raised to the original pressure in that chamber, so that the next and each succeeding stroke of the second cylinder commences with the same pressure of steam. A similar process is carried out in the remaining cylinders and steam chambers.

When steam in expanding through a succession of cylinders with intervening steam chambers leaves each cylinder at the same pressure as the steam in the chamber into which it passes, it necessarily gives theoretically the same gross work on the pistons as if it expanded to the same amount in a single cylinder. Practically however it is impossible to expand so much as 16 times in one cylinder without introducing many serious evils which bring down the power to a mere fraction of its theoretical amount; whereas the expansion of the steam to double

its volume in one cylinder can be carried out without difficulty or inconvenience.

The degree to which the steam will be superheated in the intermediate steam chambers depends on the temperature of the flue in which they are placed; but as the tubular boiler exposes a large extent of heating surface to the action of the hot gases from the fire before they come in contact with the steam chambers, no inconvenient amount of superheating is likely to occur, nor any burning out of the chambers. It is desirable to arrange the superheaters so that the hot gases may come in contact with them in the same order in which the steam goes through them, so as to act last on the coolest steam chamber.

The Surface Condenser used with the engine previously described is shown in Fig. 3, Plate 24. It consists of a number of straight wrought iron tubes fixed vertically in a chamber P, closed at the upper ends and screwed by their open ends into a thick plate at the bottom, as shown enlarged to one quarter full size in Fig. 5, Plate 25. These tubes contain the cold water, which circulates rapidly through them, and their outer surfaces are exposed to the steam to be condensed. Each of the tubes contains a smaller tube open at both ends, and through this inner tube the condensing water is driven up by the pump S, Fig. 3, to the top of the outer tube, and then descends through the annular space between the tubes, as shown by the arrows in Fig. 5. The object of this arrangement is to prevent the possibility of any straining and consequent leakage of the tubes from heating or unequal expansion, by having all the tubes fixed at one end only, with the other end left free. The condenser in use has about 20 square feet of cooling surface for every cubic foot of water condensed per hour, and the vacuum obtained by it varies from 26½ to 28½ inches of mercury, notwithstanding that the air pump T, Fig. 4, is exceedingly small in proportion.

An incidental but not unimportant advantage of using a surface condenser is that it keeps the water level in the boiler constant without any trouble to the engineer, by always returning to the boiler the exact quantity of water that has been taken out as steam. For

circulating the water through the tubes of the condenser the arrangement best suited for marine engines is a lift pump or air pump to draw the sea water through them, with a screw cock on the inlet pipe by which the supply of water can at pleasure be throttled; so that even if a leakage were to arise in the tubes of the condenser, no sea water could get in to mix with the distilled water, but on the contrary an outward leakage would occur if care were taken to keep the vacuum inside the tubes a little better than that in the condenser. In order to supply the place of any distilled water that might escape by leakage or otherwise, a small still should be attached to the boiler, heated by means of a coil of steam pipe of which one end communicates with the steam room of the boiler whilst the other is over the hot well and is provided with a screw cock. As soon as this cock is allowed to drip or run, the still will begin to work and replenish the boiler with distilled water through the usual channel of the condenser.

Mr. E. A. COWPER observed that the advantages of high pressure steam were now generally acknowledged, and the pressure of steam in engines had been gradually raised, having risen now in locomotives from 100 lbs. to 150 and even 200 lbs. per square inch. He therefore thought it was desirable to look boldly at the advantages of a much higher pressure, as had been done in the paper just read, where it was proposed to work with 500 lbs. steam, and the engine described had been worked at that pressure to show the advantages practically. The boiler he had seen working at that pressure, and it certainly appeared a very strong construction. With a high pressure of steam he had long considered the use of a surface condenser and distilled water in the boiler essential to economy, and it was attended with advantages of great importance: the necessity for cleaning the boilers was done away with, as no deposit could ever be formed, and the water level was

maintained constant, whatever quantity of steam was taken off by the engine; while there was only 1-25th as much water to pump out of the condenser, and, what was of even greater importance, the pumping out of the air introduced with the injection water in ordinary condensers was saved.

Mr. PERKINS said the indicator diagram shown from the first cylinder was taken from the passage between the valve and cylinder, because there was not room to get the indicator on the top of so small a cylinder. The boiler pressure was 570 lbs., and the spring of the indicator made the figure jump up to 600 lbs. when the steam was admitted, but the actual pressure was only 510 lbs. total at the time of cutting off. The steam was cut off at 1-4th of the stroke in the first cylinder and expanded down to 170 lbs. total pressure or about 3 times, when it was exhausted into the second cylinder, the pressure dropping to 88 lbs. total in the passage between the cylinders; from the second cylinder it was exhausted at 36 lbs., and dropped to 30 lbs. in the passage to the third cylinder, from which it was let out into the condenser at a pressure of 27 lbs. total, making the whole expansion from the commencement amount to about 19 times.

Mr. E. A. COWPER remarked that as the pipe from the cylinder to the indicator was long, there might be an accumulation of water in it which would cause the indicator to jump by its momentum. He enquired whether the drop in the pressure in exhausting from one cylinder into the next was owing to the passages between the cylinders being large.

Mr. PERKINS replied that the passages were not large, but the drop was occasioned by the steam being cooled from want of sufficient heat in the casing to maintain the temperature. The pipe from the cylinder to the indicator had to be made long in order to keep the packing of the indicator from being burnt by the high temperature of the steam; consequently the pressure was probably somewhat lower in the indicator than in the cylinder.

Mr. W. BOUCH enquired whether the indicator diagrams varied with the speed of running, and what was the speed when they were taken.

Mr. Perkins replied that there was a variation in the diagrams according to the speed of the engine, but they were not so reliable at a high speed, on account of the oscillation of the indicator, and the engine was therefore worked at only about 60 revolutions per minute whilst the diagrams were being taken and slower than would be the case in actual work, when it would run at about 100 revolutions per minute.

Mr. M. Smith enquired how long the engine had been at work, and what was its cost.

Mr. Perkins replied that the engine had not yet been applied to regular work, but had been working experimentally during the last six months with a friction break to test the practicability of the plan. The cost was about the same as that of marine engines, namely £50 to £60 per nominal horse power including the boiler, the engine indicating however from 2½ to 3 times the nominal horse power.

Mr. E. A. Cowper observed that the larger engine suggested in the paper with the steam expanded through four cylinders working in pairs on cranks at right angles would give a very uniform driving power, with probably only from 10 to 25 per cent. variation in driving power throughout the revolution, according to the point of cutting off in each cylinder.

Mr. W. Weild asked why the driving shaft was placed below the cylinder, for manufacturers generally objected to having the engine inverted, from the greater difficulty of keeping it in order and doing repairs.

Mr. Perkins said in the present engine they had only taken the common form used for propeller engines, but for manufacturing purposes the engine would be reversed in position, and it might be arranged in any way to suit convenience.

Mr. W. May had seen the engine at work when it was driving the friction break, and it appeared a useful step towards improved economy in steam engines, by showing the practicability of much greater pressure and expansion, whether the details of construction at present adopted were considered the best or not. The boiler seemed in good order and perfectly safe for the high pressure of steam; it could be easily repaired by the removal of any portion without interfering with

the rest of the boiler. The temperature in the chimney was remarkably low, the iron casing being so cool that the hand could be borne on it.

Mr. J. Cochrane enquired whether there would not be some difficulty with the boiler from the chance of the small connecting pipes getting choked up if the water were not perfectly pure.

Dr. Williamson said that in larger boilers larger connecting pipes would be used, and the smaller pipes were certainly liable to become incrusted with common water; but where pure water was used with a surface condenser, there was nothing that could ever get into the pipes to choke them, and it was not contemplated to work a boiler of this construction except with a surface condenser. The only way to ensure safety and durability in such a boiler or in any other kind of boiler was to avoid the evil of incrustation by using a surface condenser, without which he thought no boiler ought ever to be worked at high pressures. In the present boiler no incrustation had as yet been experienced nor could any take place, but the boiler would be spoiled directly if used with ordinary water and an injection condenser. The principle of surface condensers had been established by many previous trials, and various forms of construction had been devised. The gridiron condenser on Mr. Cowper's plan had been successfully employed, having the steam passed through a set of horizontal pipes with water continually trickling over them outside, whereby a vacuum of 29½ inches of mercury was obtained and kept up for a long time. This was a very effective form of surface-evaporative condenser, and the only objection to its use was that it was bulky and inconvenient on board ship, on which account he preferred something more like Hall's condenser; and in order to get over the difficulty of the tubes leaking at the ends in consequence of being loosened by alternate expansion and contraction, the tubes in the condenser now described were fixed only at one end and left free at the other, and therefore could not leak as there was no strain on the air-tight joints.

The present engine was intended simply as a practical instance of using very high pressure steam, and not as the most perfect mode of working the steam, but to show that working at 500 lbs. pressure was as easy as at ordinary moderate pressures. The pressure of steam

already in use in other engines had risen gradually to 200 lbs., and in using such a boiler as now described much higher pressures might be employed with confidence, on account of the great strength of the small tubes, the boiler having been proved by water pressure up to 3000 lbs. per square inch.

Mr. J. Murphy considered tubular boilers were decidedly superior in principle to plate boilers for high pressures, on account of their greater safety and efficiency; they were in use in many American steamers, where the tubes were all of the same diameter and joined at the ends by curved bends screwed on, giving a continuous passage through the tubes. He enquired how the junctions were made in the boiler now described, and whether there would not be some difficulty in getting out any part of the boiler for repairs, on account of the number of joints.

Mr. Perkins replied that each section of the boiler was connected by a single vertical pipe at top and bottom to the main cross tubes, and this connecting pipe had a right-handed thread at both ends, the thread being made long enough to allow of completely detaching any section without interfering with those on either side. The intermediate vertical connecting pipes were all fixed with right and left handed screws. The boiler tubes were 2¼ inches bore and ⅜ inch thick, and were butt welded so as to have the same thickness throughout and sufficient to allow of screwing; and the connecting pipes were ⅞ inch bore and ¼ inch thick. Thin tubes were generally liable to be defective in material, but these were such as he had used extensively for many years in hot water warming apparatus working under high pressure with complete safety.

Mr. F. J. Bramwell had seen the engine at work and considered it useful and interesting in illustrating the economy of steam power by using increased pressure and greater expansion. The mode of estimating the evaporative duty of the boiler by measuring the consumption of water with a meter he thought was liable to error if not checked by observing the total increase of heat in the condensing water, in order to allow for water carried over as priming, which otherwise made the evaporative results appear greater than they really were. It was necessary to adopt this check in calculating the

evaporative duty, because priming was sure to occur, except in boilers with very large steam room where there was no violent ebullition. He had known an instance where the boilers in some of the American steamers, made with a number of vertical tubes, had been stated to give a very high evaporative duty; but when their actual performance was tested with a meter, it was found that 43 lbs. of water were fed into the boiler per indicated horse power per hour, which certainly could never have been all converted into steam, but showed that priming must have taken place extensively, and that the apparent high evaporative duty was a mistake.

Mr. E. A. Cowper observed that vertical tubular boilers were especially liable to priming, from the comparatively small area of water surface for the liberation of the steam.

He proposed a vote of thanks, which was passed, to Dr. Williamson and Mr. Perkins for their paper, and hoped it would lead to the further development of the important advantages of high pressure steam with great expansion.

The Meeting then terminated.

PROCEEDINGS.

31 July and 1 August, 1861.

The Annual Provincial Meeting of the Members was held in the Music Hall, Surrey Street, Sheffield, on Wednesday, 31st July, 1861; Sir William G. Armstrong, President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

George Addenbrooke,	Darlaston.
Henry Bessemer,	Sheffield.
William Esson,	Cheltenham.
Sampson Lloyd Foster,	Wednesbury.
Edward Green, Jun.,	Wakefield.
William Haden,	Dudley.
Peter Haggie,	Gateshead.
Joseph Bennett Howell,	Sheffield.
Robert Jackson,	Sheffield.
Thomas William Jeffcock,	Sheffield.
Joseph Mitchell,	Worsbro' Dale.
Loftus Perkins,	London.
Thomas William Plum,	Blaenavon.
Thomas Edward Vickers,	Sheffield.

HONORARY MEMBER.

Alexander W. Williamson,	London.

The President then delivered the following address:—

ADDRESS OF THE PRESIDENT.

The era of Mechanical Engineering may be regarded as dating from the period when the Steam Engine first became applicable through the genius of Watt to the production of continuous rotary motion. The introduction of separate condensation, which had previously been effected by that great man, may justly be considered the chief foundation of his fame. But it was not until he had succeeded in converting the reciprocating movement of the piston into rotary action that the steam engine became available for every variety of purpose requiring the employment of motive power.

While Watt was thus engaged in rendering the steam engine capable of universal application, the great invention of Arkwright, the author of the modern system of spinning, was struggling into notice. This was quickly followed by that of Cartwright, the designer of the power loom, which marked a new era in the art of weaving. These inventions were each destined to play a part of incalculable importance to mankind, and to afford employment to the giant power which Watt had raised from infancy to maturity. They have distributed cheap and abundant clothing over the face of the earth; and while they have conferred so great a boon on the whole human race, they have been and still continue to be the chief source of this country's wealth. These great advances in textile manufactures were purely utilitarian in their character. It was reserved for France to complete the work, and extend the humanising influence of ornament and taste, by giving birth to the Jacquard loom.

Nearly simultaneous with these inventions were those of Cort, which though of a widely different character have produced fruits of equal importance. They have had the effect of enormously facilitating the conversion of cast iron into the malleable form, and have enabled

us to roll it into bars of every variety of section, thus paving the way for the introduction of railways, and rendering iron available for the construction of ships, and the various structures on land in which it is now employed. Following down the history of the manufacture of iron from the days of Cort, we come at a later date to the introduction of the steam hammer by Nasmyth, and of the hot blast by Neilson. The former has rendered practicable the fabrication of those large masses of iron which are now daily required in the construction of heavy machinery; while the latter has had the effect of diminishing the cost and extending the application of the material.

Turning next to the subject of Steam Navigation, we find that the first attempt to propel a vessel by steam was made by Miller, on the Forth and Clyde Canal, soon after the adaptation of the steam engine to rotary motion by Watt. At a somewhat later date, though with more success, Fulton constructed a steam vessel in America: but the achievements of both were feeble foreshadowings of that mighty growth, which in the course of half a century has covered the ocean with steamers; advancing step by step from an insignificant boat on the Clyde to that wonder of our age, the "Great Eastern" steamship. This great development, although so rapid, has nevertheless been so gradual that the adoption of the screw propeller is the only prominent feature in its progress. The introduction of the screw, which is chiefly due to the perseverance and enterprise of Francis Smith, has rendered the power of steam available for war vessels, while in sea-going steamers generally it seems destined to displace entirely the earlier invention of the paddle.

As in the case of steam navigation, the propulsion of carriages by steam power on land had its origin in very small beginnings. From the days of Watt, who first suggested the application of the steam engine for this purpose, up to the time when George Stephenson, the illustrious first President of this Institution, devoted with wonderful perseverance the inventive powers of his mind to its perfection, the Locomotive Engine had attained no practical value. But in the hands of Stephenson it took as great a stride as did the condensing engine in the hands of Watt. The ever memorable "Rocket," which carried off the prize at the opening of the Liverpool and Manchester Railway,

became the type of all succeeding locomotives, just as the condensing engine as left by the original master has remained the standard of that class of engines. Of all the achievements of mechanical engineers the locomotive engine is the greatest. As a work of skill it presents the most remarkable instance of strength and power, combined with lightness, that can be found in the whole field of mechanical engineering; while in point of utility it has served more than any other invention to develop the resources of every country in which it has been employed.

By promoting centralisation, steam communication has made good government cheaper and more practicable. It has strengthened the hands of the executive, broken down provincialism, opened out new markets for produce, established new fields of supply, equalised prices, and facilitated colonisation. It has given fresh life to old nations, and added to the vigour of new ones. A Greek poet with seemingly prophetic import has described the business of the road-making sons of Vulcan to be that of converting the uncivilised places of the earth into civilised. True sons of Vulcan, the god of iron and of fire, are those men who in our time have been the pioneers of civilisation, by giving steam-worked railroads to the world, and applying the steam engine on the highways of the ocean.

While the steam engine was being applied to manufacturing purposes and to locomotion on land and by water, there was one branch of industry in which it remained neglected. Whether it be that ancestral usages are more reverenced by the owners and tillers of land than by the more progressive inhabitants of cities, or whether the steam engine was regarded by the rural population as an upstart rival of the horse, with which their pleasures and pursuits were so much associated, certain it is that the cultivators of the soil were the last to resort to the agency of steam. But agriculture is now added to the domain of science, and under her sway the steam engine has been applied to numerous purposes of husbandry. Some of these have involved peculiar difficulties, and perhaps in no case have the resources of mechanics been more severely taxed than in applying steam power to the operation of ploughing. Much interest at present attaches to this subject, in connexion with the recent exhibition of the Royal

Agricultural Society at Leeds, and the successful results obtained on that occasion by Fowler and by Howard, both members of this Institution.

The development of these several inventions has involved the necessity of great improvements and refinements in tools and constructive machinery; and the name of Whitworth, another of your Presidents, will go down to posterity as that of the man who has been chiefly instrumental in raising to its present height this important branch of mechanical engineering. But it must not be forgotten that, whatever may be the perfection of tools, manual dexterity will ever be the foundation of excellence in construction; and if the skill of the artificer had not kept pace with the progress of invention, the mechanical productions of the present day would not have been possible. It is a proud reflection for Englishmen that nearly all the names connected with the wonderful series of mechanical triumphs to which I have adverted have been those of their fellow countrymen; and this fact is the more remarkable when we consider that in earlier times our country had been singularly sterile in the production of this species of talent.

In thus glancing at the history of mechanical science during the last eighty years, we see how entirely our successes have been based upon the possession of that metal with which nature has supplied us in the greatest abundance. Without iron all our skill and ingenuity would have resulted in comparatively nothing; and had it not been endowed with that singular property of hardening by sudden immersion after previous conversion into steel, we should have been deprived of the means of cutting and shaping it to those accurate forms which mechanical constructions require. Its property of welding is almost equally essential to its utility; and the combination of these remarkable qualities in one metal, coupled with the fact of its natural localities being generally identical with those of coal, affords the most striking instance of adaptation to the purposes of man that can be found in the mineral kingdom. It is the iron and not the golden age which is the true age of civilisation; and England has led the way in the march of progress, chiefly through her skill and energy in producing this metal and applying it to mechanical purposes.

Iron, unlike all other metals, has three phases of existence: cast iron, wrought iron, and steel: each equally useful, and yet so different as to be virtually separate metals. In the manufacture of steel the town of Sheffield enjoys an unrivalled eminence, and our discussions on this occasion will naturally be directed to those various questions of peculiar interest which at present apply to that most useful product.

I have hitherto spoken of the mechanical arts as applied only to the purposes of peace; but I have yet to refer to the darker side of the picture in speaking of their application to the purposes of war. We shall all agree in condemning war, and deploring the suffering it entails; but we must not regard it as destitute of all admixture of good. The conquests of ancient Rome scattered the germs of civilisation over the whole of the then known world, and similar effects have attended many of the conquests of more modern times. War also affords a field for the exercise of some of the noblest attributes of our nature: courage, patriotism, self-devotion, and honour, have found their brightest examples amongst those who have followed the profession of arms: and the homage which is universally paid to military distinction shows how contrary to our instincts are the tenets of those moralists who place war and crime in the same category. But whatever opinions may be held on this subject, it is useless to take utopian views of the duties of nations and the principles which ought to regulate their intercourse. We know that nations, like individuals, are liable to quarrel; and when they do so, having no common jurisdiction to control them, they resort to arms. So long therefore as any one nation maintains its armaments, it is an absolute necessity that others should do the same, unless they choose, by their inability to resist, to tempt a rupture, and are content to succumb in the event of its occurrence. Our neighbours the French, always forward in everything appertaining to war, have of late years devoted their energies to two most important subjects: the rifling of ordnance, and the application of defensive armour to ships. Their advances have necessitated similar steps on our part, and we have certainly no reason to suppose that we are behind them in the race.

With the first of these subjects I have been personally much concerned, and I have also had opportunities of observing the merits and defects of the various descriptions of armour plates with which experiments have been made by the direction of government. I need scarcely say that up to the present time cast iron has been almost exclusively employed in the construction of heavy ordnance; but guns made of that material have not been found adequate to resist the more severe strain incident to the use of elongated rifled projectiles. This inadequacy of strength becomes the more decided as the magnitude of the gun is increased, and since a growing demand exists for more powerful artillery, the use of cast iron for its construction seems to be entirely precluded. It is said, and I believe with truth, that in America the manufacture of cast iron ordnance has been so far improved by applying water to cool the casting from the interior, as to enable serviceable guns of this material to be produced of much larger bore than have been made in England. But it appears that these guns have not been rifled, and are intended to be used only with hollow projectiles. This success therefore affords no reason for coming to a different conclusion as to the unfitness of cast iron for the construction of rifled guns designed to project solid shot, especially when the dimensions are large. Even when strengthened by wrought iron hoops, the tendency of cast iron in a gun is to become weaker by every succeeding discharge. This is owing to minute fractures occurring in the bore, generally near the vent, and gradually extending until they terminate in the rupture of the gun. If therefore cast iron guns are to be made available at all as rifled ordnance, it can only be by confining their use to hollow projectiles and light charges.

But if the same indulgence were extended to wrought iron guns, equal efficiency would be obtained with half the weight of metal; and on this ground alone the superiority of the latter is decisive. Wrought iron, made either from bloom or from puddled ball, must necessarily consist in the first instance of a congeries of welds or joinings. The smaller the mass and the more it is reduced under the rolls or hammer, the more perfectly will it be united; but when a large block is forged from an aggregation of blooms it is almost impossible to render it homogeneous throughout. The flaws in such a forging will

generally be drawn out by the process of hammering in the direction of the length, and will therefore not materially affect its strength in reference to longitudinal strains: but if the mass be subjected to an explosive force acting from the interior, as in a gun, the presence of such flaws becomes fatal. Wrought iron therefore applied as a solid block to the construction of guns I hold to be even more objectionable than cast iron; for although a wrought iron gun thus made, if it happen to be sound, may possess greater powers of resistance, yet it must always be more subject than cast iron to concealed flaws, and on that account be more uncertain and treacherous. If iron after its conversion to the malleable form could be fused, all welds would be obliterated and the mass rendered uniform throughout. Such a material would merit the appellation of homogeneous iron; but the metal which now bears that name is of a different nature, being merely a species of cast steel.

The crystalline form assumed by steel in solidifying from the liquid state always renders the material in the first instance hard and brittle; and it is only in the subsequent process of hammering that it acquires ductility and toughness. This alterative process of hammering is perfectly effectual when the thickness of the steel is small; but when it is wanted to be forged in a large mass it appears to be a matter of the utmost difficulty to effect the required change. It is seldom that the enterprise of English manufacturers is exceeded by that of foreigners, but in the production of steel forgings of large dimensions Krupp of Essen has taken the lead of all steel makers in this country. He has met the difficulty of toughening large masses of cast steel by using hammers of extraordinary weight; and I believe that equal success will never be attained in England without adopting similar measures.

It will be a great era in metallurgy when a material possessing the toughness and ductility of wrought iron combined with the homogeneous character of a cast metal can be economically supplied in large blocks. But whatever the march of improvement may effect, I doubt whether such blocks can yet be produced at a cost which would admit of their extensive application. I am glad however to see that papers are to be read at this meeting which may be expected to bear upon this important

subject; and amongst the names appended to those papers we are fortunate in having that of Bessemer, whose exertions in this field of enquiry have attracted so much attention.

The preceding observations on the application of iron to the construction of artillery would not be complete without some allusion to the system of manufacture which I have myself adopted, which may be designated the "coil system." When malleable iron is rolled into bars, its crystallisation assumes a fibrous form, causing the bar to resemble a bundle of threads, strongly adhering to each other, but possessing their chief tenacity in the direction of their length. The compressing power of the rolls is also such as generally to eliminate all imperfect welds, or if any remain they are drawn out parallel with the fibre of the iron. To realise in a cylinder the advantage of this fibrous structure, it becomes necessary to coil the bar into a spiral, and to unite the folds by welding. The lines of welding will then be nearly transverse to the cylinder, in which direction they have little tendency to weaken it when exposed to a bursting force, even should they not be perfectly sound. There is a limit to the thickness of bar which it is convenient to bend into a spiral; and in making a gun on this system the required diameter is made up by applying successive layers of coils, each layer being shrunk upon the one beneath. This mode of construction has the advantage of affording the opportunity of discovering and rejecting all defective parts as the work proceeds; and guns may be thus built up to almost any size without encountering any of those difficulties and liabilities which are met with in forging large blocks whether of steel or iron.

With regard to the great question as to the ultimate effect of artillery against ships protected by defensive armour, I believe that whatever thickness of iron may be adopted guns will be constructed capable of destroying it. At the same time I am of opinion that iron-plated ships will be infinitely more secure against artillery than timber ships. The former will effectually resist every species of explosive or incendiary projectile, as well as solid shot from all but the heaviest guns, which can never be used in large numbers against them. In short it appears to me to be a question between plated ships or none at all, at any rate so far as line-of-battle ships are concerned.

With respect to the quality of the material best adapted to resist the impact of shot, this subject is engaging much attention in the town of Sheffield and the iron districts generally. So far as my own observation and experience go I may say that hardness and lamination are the conditions most essential to avoid. In striking a plate the tendency of a shot is to fracture rather than to pierce the material. When penetration is effected the hole is of a broken character, and not such as would be made by the cutting action of a punch. The softer the iron therefore the less injury it will sustain; and I apprehend that steel in every form will from its great hardness be found less effective than wrought iron, while its cost would be very much greater. As regards lamination it has been clearly ascertained that a given thickness of iron made up of successive layers of thin plates is very much weaker for the purpose of armour than the same thickness in the solid form. But a laminated plate, by which I mean a plate having the layers composing it imperfectly united, must be regarded as an aggregation of separate plates, so that the strength derived from continuity is wanting. If this tendency to lamination could be obviated, rolled plates would in my opinion be preferable to forged, since the iron would acquire a more fibrous condition; but the existence of this liability appears to turn the scale in favour of forging. I hope the time is far distant when these great questions concerning attack and defence may receive a practical elucidation in actual warfare; but I trust that in the course of our efforts to solve them, discoveries may be made which will be as useful for the purposes of peace as for those of war.

Before concluding, I am tempted to advert to a subject intimately connected with mechanical progress, but upon which much difference of opinion may exist. That dauntless spirit, which in matters of commerce has led this country to cast off the trammels of protection, has resulted in augmented prosperity to the nation, showing the injurious tendencies of class legislation when opposed to general freedom of action. Would that the same bold and enlightened policy were extended in some degree at least to matters of invention. Under our present patent laws we are borne down with an excess of protection.

We are obstructed in every direction by patented inventions which will never be reduced to practice by those who hold them, but which embrace ideas capable of useful application if freed from monopoly. The merit of invention seldom lies in the fundamental conception, but is to be found in the subsequent elaboration, and in the successful struggle with difficulties unknown to the mere theorist; which often require years of labour, blended with disappointment, for their removal. Nothing can be more irrational therefore than to accord equal privileges to the mere schemer and the man who gives actual effect to an invention. Primary ideas ought to be the common property of all inventors; and protection, if we are to have it at all, should be sparingly awarded to those persons alone who by their labour and intellect give available reality to such ideas.

Apart from the impolicy of the present indiscriminate system, its operation is unjust. Philosophers who furnish the light of science to guide to useful discovery go altogether unrewarded and unrecognised. Practical men, who like Watt and George Stephenson devote the best part of their lives to perfecting inventions of immense importance to the world, seldom derive from patents any greater emolument than would flow to them without the aid of a restrictive system; while they are frequently involved in tormenting litigation about priority of idea. On the other hand we see numerous cases of disproportionate wealth realised by persons whose only merit has been promptitude in seizing upon and monopolising some expedient which lay upon the very surface of things and required no forcing atmosphere of protection for its discovery. Finally, injustice is done by the existing law to those men who have no desire for monopoly, but who are compelled to become patentees for no other purpose than to prevent their being excluded from carrying their own ideas into practice.

For my part I incline to think that the prestige of successful invention would as a rule bring with it sufficient reward, and that protection might be entirely dispensed with. On this point however I speak with hesitation; but it is at all events certain that extensive reform is urgently required in this branch of legislature, and that the advance of practical science is now grievously obstructed by those very laws which were intended to encourage its progress.

Having now called to your remembrance the triumphs which have already been accomplished in mechanical science, and having directed your attention to some of the subjects which at the present time merit your consideration, it only remains to express my hope that the genius, enterprise, and intelligence, which have hitherto distinguished your profession may continue to bear fruits worthy of the past; and that the proceedings of this Institution may serve to guide and stimulate the efforts of its members.

Mr. J. Fenton moved a vote of thanks to the President for his address, which was passed.

The following paper was then read:—

ON THE MANUFACTURE OF STEEL RAILS AND ARMOUR PLATES.

By Mr. JOHN BROWN, of Sheffield.

Steel Rails.—One of the most important items in the cost of railway maintenance is the renewal of Rails, and it is therefore natural that much attention should have been paid to the various methods proposed for giving greater durability to the rail. It is unnecessary to enter into any statement of facts as to the short time that ordinary rails last when exposed to the wear of main lines: experience has shown the want of some means by which their duration could be prolonged, and in the manufacture of rails it is now always expected that the quality of the material and the method of piling shall be distinctly stated before any large amount of work is undertaken.

No ordinary material or method of piling or making the finished rail will however resist the crushing action of modern locomotives, and extraordinary means have been sought to accomplish this much desired object. Amongst the most important of the methods hitherto used for this purpose is that of forming the wearing surface of the rail entirely of steel, by introducing a bar of steel into the pile and rolling it out so as to unite it with the iron body of the rail. Another method is to submit the surface of the ordinary iron rail to a process of conversion in a furnace specially adapted, thereby casehardening the outer coat or skin of the wearing portion of the rail. Both of these processes have many advocates, and to a certain extent they fulfil their object; still they are open to the serious objection that only the crust or skin of the rail is rendered hard, and they do not prevent the body of the rail from yielding to the severe pressure of the wheels; lamination and splitting are only to a small

extent diminished, and though the life of the rail is prolonged, the prolongation is uncertain. The same objections apply to the puddled steel rail, and it is also liable to vary considerably in its hardness and to be at times too brittle for perfect safety. This liability to vary in quality is inseparable from the mode of manufacture as at present practised; and though many very good rails of this kind have been produced, the want of certainty in the manufacturing process seriously diminishes its value.

The introduction however of Bessemer's system has opened out a mode of producing a pure homogeneous hard and tough material, most admirably suited for the manufacture of rails; and though their cost may for a time prevent their being extensively used, there is no doubt that on every railway there are certain places where they would be laid with economy, where the traffic is so constantly severe that ordinary points and crossings have to be renewed on an average four times a year. Once laid of cast steel rails, they would give no trouble for many years.

In the Bessemer process the pig metal is reduced in a reverberatory furnace, and is then run by a trough into the blowing or converting vessel, in which air is forced through the fluid metal for about 20 minutes, or until the fluid pig is almost entirely decarbonised. A small quantity of melted pig containing a known proportion of carbon is then added, and the charge of converted metal is then transferred to a ladle from which it is poured into ingot moulds, not however by the usual mode of canting the ladle, but by opening a valve in the bottom of the ladle, which allows only the pure metal to run out into the moulds. The ingots are cast of such weight and form as are necessary for the production of each rail. Thus for a 6 yard rail of 84 lbs. per yard, the ingot requires to be 9 inches square and 26 inches long. This ingot is hammered down to 6 inches square and 5 feet long, and then rolled in the ordinary way. It will be evident that the only limit to the length of the rail made in this simple manner is either the weight of the ingot which can be produced or the length of the rolling mill or heating furnace. It is as easy to produce long lengths as short ones; and in this respect the above method has some advantage over piling.

There is no tendency to lamination in this perfectly homogeneous material, and its toughness and ductility are remarkably shown by the specimens exhibited, all of which have been twisted and bent while cold. Its tensile strength is upwards of 40 tons per square inch.

Cast steel rails are not an entire novelty; for several years ago a few were made at Ebbw Vale and were laid at the bridge at the north end of the Derby station, and there they are at the present time perfectly sound and good, whilst the neighbouring iron rails have been many times worn out and replaced. But these rails were made at a great expense from ingots cast in the old or usual method, and the imperfect appliances then existing made it impossible to introduce them commercially. Still the experiment at Ebbw Vale has clearly proved the far greater power of resisting wear and tear possessed by the steel rails; and now the method of producing ingots by the Bessemer process enables rails to be produced which bid fair to become in truth a really "permanent way."

Armour Plates.—In the further portion of the present paper, on the manufacture of Armour Plates, the writer's principal object is to elicit discussion upon this important subject; and as but a very short time has elapsed since the rival powers of the penetration of shot and the resistance of plates have been so seriously and energetically tested, it is necessary to speak with diffidence upon a matter which on all hands is allowed to be as yet imperfectly determined. No limit has yet been assigned to the magnitude of future artillery, nor has any degree of impenetrability of iron plates been declared unattainable. The manufacturer's business is simply to make the best and strongest armour which at the present time is wanted, and leave future possible requirements to be dealt with when the benefits of experience have been obtained. It does not come within the province of this paper to discuss the several questions involved in determining the best form of vessel to carry the weight of armour, nor to settle the resisting power of iron as compared with wood. The iron-maker's problem is how to produce the largest plate of iron of the maximum degree of toughness.

Two methods of producing large masses of wrought iron have been in use: the first by the process of building up under the steam hammer,

and the second by building up under the rolls. Under the steam hammer, the plate is produced by welding together lumps or masses of scrap iron, each mass of scrap being added and welded to the end of the plate, until it reaches the required length. Plates made in this way have been seriously objected to on account of their brittleness; and it is reasonable to suppose that this mode of manufacture is somewhat likely to induce brittleness. There can hardly be any continuity of fibre in a plate forged from masses of scrap iron, perhaps of different qualities, each at different heats; the nature of the weld and its form, and the repeated cooling and re-heating of the plate, are also adverse to its possessing great toughness. The rolled plates have been found more uniform in quality and of greater toughness than the hammered; and though the difficulties in their manufacture are grave, there is no departure from the ordinary practice followed in making large plates for other purposes. The difficulties which do exist are chiefly due to the immense weight and size and the intolerable heat of the mass, which must be dealt with while at a welding temperature.

The general size of the armour plates required for the plated frigates is from 15 to 18 feet long, from 2 feet 6 inches to 3 feet 10 inches wide, and 4½ inches thick. The weight therefore of the finished plate ranges from 60 to 110 cwts.; and in the unfinished state it comes from the rolls at 80 to 140 cwts. From 3 to 4 inches is cut off the sides, and 10 or 12 inches from each end; and in this item of waste the hammering process has an advantage over the rolling.

The mode of manufacture of a 5 ton plate is as follows. Bars of iron are rolled 12 inches broad by 1 inch thick, and are sheared to 30 inches long. Five of these bars are piled and rolled down to a rough slab. Five other bars are rolled down to another rough slab, and these two slabs are then welded and rolled down to a plate of 1¼ inch thick, which is sheared to 4 feet square. Four plates like this are then piled and rolled down to one plate of 8 feet by 4 feet and 2½ inches thick; and lastly, four of these are piled and rolled to form the final entire plate. There are thus welded up together 160 thicknesses of plate, each of which was originally 1 inch thick, to form the finished 4½ inches, making a reduction of 35 times in thickness; and in this operation from 3500 to 4000 square feet of surface have to be

perfectly welded by the process of rolling. It is not surprising that even with the greatest care blisters and imperfect welds should exist and render the plate defective; this is the chief difficulty to be overcome, and a very serious one it is; and as the magnitude and weight of the plate increase so does also the liability to failure.

The final operation of welding the four plates of 8 feet by 4 feet by 2½ inches is a very critical matter. To bring a pile of four plates of these dimensions up to a perfect welding heat all through the mass, without burning the edges and ends of the plates most exposed to the fire; to drag this pile out of the furnace, convey it to the rolls, and force it between them, in so short a time as to avoid its losing the welding heat, is a matter of greater difficulty than those unacquainted with the work would imagine. The intensity of the heat thrown off is almost unendurable, and the loss of a few moments in the conveyance of the pile from the furnace to the rolls is fatal to the success of the operation.

Figs. 1, 2, and 3, Plates 27, 28, and 29, show the arrangement of the armour plate mill at the writer's works. Fig. 1, Plate 27, is a general plan of that portion of the works: Fig. 2, Plate 28, is an enlarged plan of the heating furnace and rolls: and Fig. 3, Plate 29, an elevation of the furnace and rolls.

The pile of four plates A, Figs. 2 and 3, Plates 28 and 29, which united form the finished plate, is heated in a special furnace B, and is drawn out by a liberating chain attached to the roll on to an iron carriage C which conveys the pile to the rolls D. The carriage C travels upon a line of rails let into the ground; and close in front of the roll frame is a small incline E upon the railway, which lifts up the front of the carriage at the moment of its arrival at the rolls, and enables it to deliver the pile upon the fore-plate. As the plate passes through the rolls it is received on the other side upon a roller frame F, which is set at a considerable inclination towards the rolls, so that the tendency of the plate is to return. The rolls are then reversed; and the plate which was pressing against them passes back through, and is received upon the carriage C; and again the operation is repeated until the 10 inches thickness is reduced to 4½ inches.

The plate is then lifted off the carriage C by the crane G, and deposited upon a massive cast iron straightening bed H, and an iron cylinder I weighing 9 tons is rolled over it to and fro, being pinched along by hand levers, until the curvature which the plate has acquired in the rolling is entirely removed. As soon as the plate is sufficiently cool, it is lifted off the straightening bed H by another crane K, Fig. 1, Plate 27, and laid upon the planing machine L, where the final operation of planing its sides and ends is completed.

Mr. Brown exhibited specimens of the steel rails, fractured to show the quality of the metal; and pieces of the rails that had been bent double while cold without fracture: also a piece of 75 lbs. double headed rail which had been drawn down hot into a bar 1 inch square and then twisted cold without showing any tendency to cracking or splitting.

The Chairman enquired where the steel rails were laid, and how long they had been down, and what appeared to be their durability.

Mr. Brown said there were not many rails laid down at present in this country, and they had been used hitherto mainly on the continent; the longest had been down about six or seven months at the new Pimlico Railway Station in London, and had proved very satisfactory: they were answering admirably, and were in as good condition now as when laid down; and a set of steel points and crossings had also been in constant use for seven months at the same station. There were also some of the steel rails more recently laid on the Caledonian, Lancashire and Yorkshire, London and North Western, and Rhymney Railways, but these had not yet been down long enough to afford any results as to their durability.

The Chairman asked whether there had been any fractures of the rails in working, and what was the cost of them.

Mr. BROWN replied there had not been any fractures in working, and the rails showed not the least brittleness but were much tougher than wrought iron rails. The fractured rails exhibited were purposely broken at the time of rolling to show the quality of metal; and its great toughness was proved by the bent and twisted rails exhibited, which were all done cold. The cost of the rails was of course higher than that of ordinary rails, and was an objection against them on the English railways; but continental companies were willing to pay the extra first cost of a more expensive rail, provided it would wear better than the ordinary rails, and he believed the steel rails would wear out at least five ordinary rails; but none of the steel rails had been used up yet, and their durability could therefore only be estimated from their comparative appearance after a short time of wear. The price of the rails was £18 10*s*. per ton in England, and £5 or £6 more on the continent.

Mr. SAMPSON LLOYD enquired whether the steel for the rails was made by the Bessemer process.

Mr. BROWN replied that it was all Bessemer steel, and this process gave a great advantage in entirely getting over the difficulty and cost of producing such large masses of cast steel by the ordinary method.

Col. KENNEDY enquired what reduction of weight it was considered could be safely made in the rails by the use of steel instead of the ordinary wrought iron rails.

Mr. BROWN said the weight was reduced about one third as compared with ordinary wrought iron rails. The 75 lbs. double headed steel rails had been tested up to 80 tons in the centre with 3 feet length between the bearings, and the deflection was 2¾ or 3 inches without showing any signs of cracking.

Mr. J. FENTON asked how the 80 tons load was applied, whether by hydraulic pressure or by dead weights, and how it was measured; with hydraulic pressure it was sometimes difficult to ascertain the pressure correctly in measuring by safety valves. He enquired also whether the ends of the rails were fixed in the bearings during testing.

Mr. BROWN said the load was applied by hydraulic pressure and measured by two safety valves, the valve of the press, and a separate valve on Mr. Naylor's plan fixed on purposely for the experiment, to

prevent any risk of mistake. The rails were simply supported on the bearings in testing, with the ends left free.

Col. Kennedy asked whether there was any buckling of the rail under the test load.

Mr. Brown said the rails did not buckle in the least, and the surface showed no signs of cracking with so heavy a test.

Mr. B. Fothergill enquired whether any change in the crystallisation of the steel rails took place after they had been in use for some time.

Mr. Brown replied that the rails laid in Pimlico Station had been well tested by exposure to severe work for six or seven months, and were as good as when laid, without any change being perceived.

Mr. R. Williams asked whether there was any difficulty in welding the steel rails.

Mr. Brown had not tried welding them, as each rail was rolled down to the required length from a single ingot of Bessemer steel of the proper size for making the entire rail.

The Chairman enquired in reference to the manufacture of the armour plates what was the quantity of work that could be done in rolling the plates, and how many were produced per day in regular work.

Mr. Brown replied that in ordinary work with the one mill now in operation 3 plates were turned out per day of 12 hours, weighing 5 or 6 tons each; if working all the 24 hours, 5 or perhaps 6 plates per day might be made, but this would require a second furnace for heating the plates, to allow of stopping and cleaning one furnace without delaying the work.

Mr. A. B. Cochrane asked whether the 3 plates per day were turned out with one furnace.

Mr. Brown said that number of plates was made with only the one furnace; but at present they lost two or three days in every fortnight when the furnace had to stand for repairs, and if a great quantity of plates were required two furnaces would be used, so as to keep the work going constantly.

Mr. R. Williams enquired whether the piling of the iron was the same for the armour plates as for rolling ordinary plates.

Mr. BROWN replied that the piling was just the same, the only difference of the armour plates from ordinary plates being in the quality of the iron, as none but the best description of scrap was used in the pile.

Col. KENNEDY enquired what experiments had been made on these armour plates to determine their power of resisting shot.

Mr. BROWN replied that two trials of the plates had been made some time previously, but they were not satisfactory to the admiralty or themselves; these were however their first attempts in rolling the armour plates, and they did not expect to succeed at once without some failures. He showed specimens of the broken portions of the plates, from which it was seen that the failure arose from the imperfect welding of the four thicknesses composing the armour plate in the final heat.

Two armour plates however, subsequently tried at Portsmouth in the last fortnight, had proved much more successful. The plates were 4½ inches thick, backed by 18 inches thickness of teak, and were fired at with shot 68 lbs. weight from a 95 cwts. smooth bore gun of 8 inches bore with 16 lbs. charge of powder at 200 yards range. The first plate, shown in Fig. 4, Plate 29, was 7 feet 9 inches long by 3 feet 2 inches wide: the first shot hit near a corner of the plate, at a place where the weld was imperfect, and indented the iron to some depth; the second shot also hit near the same place and indented the plate; the third shot struck the plate in the centre and made a hole right through the iron, making a crack all round the opening; the fourth shot hit near the bottom and broke the lower edge of the plate in; and the fifth shot happened to go through the hole made by the third. The second plate, shown in Fig. 5, Plate 29, was nearly double the length of the first, being 14 feet long by 3 feet 7 inches wide: the first shot indented the plate 3 inches and broke out the iron at the centre of the indentation; the second shot punched right through and broke the backing; and the third and fourth shots each broke out a hole of 12 inches diameter and smashed the backing. A portion broken off one of the plates was exhibited, which showed that the iron was much more fibrous than in the plates made in the first attempts; and he expected still more favourable results would be obtained if the iron

could be kept in a thoroughly fibrous state, so as to have a soft and tough quality, which was less easy to fracture than a hard and brittle metal.

Two of the armour plates were now in the hands of the admiralty for further experiments; and trials had just been made at Shoeburyness of two of the plates 5 inches thick, which had proved altogether most satisfactory as to the tenacity and toughness of the plates. The object was to produce armour plates capable of resisting guns of increased power, and the experiments now made seemed to show that this might be effectually accomplished by the mode of manufacture that had been described.

The Chairman observed that the quality of the plate could be better judged of when it had been actually pierced in the experiments than when only indented, as they could then see the character of the hole and examine minutely the completeness of welding of the several thicknesses. He enquired whether the Bessemer steel had been tried for the armour plates.

Mr. Brown had not yet tried it for the armour plates, but expected to do so shortly, when he had a hammer heavy enough for working it; he intended using a 4 ton Naylor's steam hammer, with the steam admitted above the top of the piston in the fall to increase the force of blow.

The Chairman remarked that he felt a great interest in the manufacture of the armour plates, as he was himself engaged on the other hand in endeavouring to increase the power of guns so as to penetrate the strongest plates that could be made. As regarded the mode of manufacturing the plates, he had seen and examined those which had been fractured in the experiments, and his own observations at present were unfavourable to rolling the several thicknesses together to form the plates, as not giving pressure enough to ensure a thorough welding in all parts. Moreover the extent of surface to be welded, amounting to 3000 or 4000 square feet in the entire manufacture of a single plate, was so great that it was difficult to conceive how a perfect weld could ever be obtained throughout, as it seemed impossible to ensure an entire exclusion of dirt from between the plates, and unless they were kept quite clean they could not be welded into a

single homogeneous plate. The difference in resisting power was very great between a really homogeneous material and one having any lamination of structure: in the latter case all portions of the material did not take their share of the strain in resisting a blow, but some were more severely strained than the rest, causing them to give way sooner; and a series of thinner plates though making up a considerably greater total thickness was inferior to a single homogeneous plate in resisting power. The very best plates he had seen at present were some small forged plates worked under a hammer at Portsmouth dockyard; these were thoroughly sound in all parts and free from impurities. What was wanted for the armour plates was a perfectly homogeneous material, and of soft texture; if they could be made like the steel rails that had been described, from a single mass of thoroughly homogeneous metal, he thought there might be a good prospect of success. Ordinary cast steel however he did not think would be so suitable as good wrought iron, on account of not being soft enough; for in all the trials he had made of cast steel for vent pieces of breech-loading guns he had found it a very unsatisfactory material, as it had no power of endurance, and though it would stand a great charge at first, it failed after continued use; and even though the firing was carried on with smaller charges than the proof charge, a point was at length arrived at when fracture took place. He could not tell whether this tendency to fracture arose from a defect in the material, by its assuming gradually a crystalline character under repeated strains; or whether a small fracture was started at first by the highest charge and then went on gradually increasing at each successive trial until the metal gave way entirely.

For forging the metal of the armour plates under the hammer, he considered the weight of the hammer was of the greatest importance; and in reference to the use of a 4 ton hammer with steam above the piston to increase the blow, it had to be borne in mind that the steam increased only the velocity of the blow without adding to the mass falling, which was not the result required; he feared the effect would be that the force of the blow would be spent on the surface of the material and would not go through to the centre of the mass like the blow of a heavier weight falling with a proportionately smaller

velocity. This appeared to him a very important consideration in forging large masses, however effective that kind of steam hammer undoubtedly was for lighter work.

He moved a vote of thanks to Mr. Brown, which was passed, for the interesting and valuable information given in his paper.

The following paper was then read:—

ON THE MANUFACTURE OF CAST STEEL AND ITS APPLICATION TO CONSTRUCTIVE PURPOSES.

BY MR. HENRY BESSEMER, OF LONDON.

The mode of manufacturing Cast Steel, which now forms so important a branch of the Sheffield trade, was discovered in the year 1740 by Mr. Benjamin Huntsman of Handsworth near Sheffield; who subsequently established steel works at Attercliffe, where his most valuable invention has ever since been successfully carried on. In its early stages many difficulties had doubtless to be overcome: materials for lining the furnaces and for making the crucibles had to be sought for and tested; the peculiar marks of iron most suitable for melting had to be determined on by numerous experimental trials; and such was the difficulty at that time of making crucibles which would stand the excessive heat of melted steel that for a long period only very highly carbonised or "double converted" steel, which required the lowest temperature, could be successfully melted. The first products of a new manufacture, even while the invention still remains in a partially developed state, but too frequently stamp its subsequent character. Thus Huntsman's cast steel, although it was acknowledged to be a pure homogeneous metal of great value for certain purposes, was still looked upon as a hard and brittle material of very limited use, not bearing a high temperature without falling to pieces, and quite incapable of being welded: even within the last few years this has been the popular idea of cast steel. Improvements in its manufacture have however from time to time been introduced; and steel of a milder and less brittle character has long been made, capable of welding with facility and working at a high temperature without falling to pieces. Its uses have consequently been greatly extended, and the employment of cast steel for the best cutlery and edge-tools has now become universal; indeed the excellent quality of the cast steel at present made in Sheffield for these purposes is

scarcely to be surpassed. Of late years several of the most enterprising manufacturers have sought to introduce cast steel for a variety of other purposes besides those for which it was originally employed, and it is now used in some form or other in almost every first class machine. Its employment as a material for founding bells and various other articles in clay moulds, as carried out by Messrs. Naylor and Vickers, and the introduction of a valuable material by Messrs. Howell and Shortridge, under the name of homogeneous metal, are prominent examples of the successful adaptation of cast steel to engineering purposes.

The manufacture of cast steel by Huntsman's process is so extensively practised and is so well known that it is unnecessary to do more than recall to mind that crude pig iron has first to go through all the stages of melting, refining, puddling, hammering, and rolling, in order to produce a bar of malleable iron as nearly pure as the most careful manipulation in charcoal fires can make it. Bar iron, on which so much labour, fuel, and engine power have been expended, thus becomes the raw material of this most expensive manufacture. In order to convert the wrought iron bars into blister steel, they are packed with powdered charcoal in large firebrick chests, and are exposed to a white heat for several days; the time required for heating and cooling them extending over a period of 15 to 20 days. When thus converted into blister steel they are broken into small pieces and sorted according to the quality of the steel, which sometimes differs even in the same bar. For melting this material powerful air furnaces are employed, containing two crucibles, into each of which are put about 40 lbs. of the broken blistered steel. In about 3 hours the pots are removed from the furnaces, and the melted steel is poured into iron moulds and formed into ingots of cast steel, from 3½ to 4 tons of hard coke being consumed for each ton of metal thus melted. When large masses of steel are required, a great many crucibles must be got ready all at the same moment, and a continuous stream of the melted metal from the several crucibles must be kept up until the ingot is completed, since any cessation of the pouring would entirely spoil it: hence in proportion to the size of the ingot are the cost and risk of its production increased. The ordinary manufacture of cast steel is

therefore obviously conducted at a great disadvantage. If cast steel is to supersede wrought iron for engineering purposes, it will be necessary to cease employing wrought iron as a raw material for this otherwise most expensive mode of manufacture.

The extremely high temperature requisite to maintain malleable iron in a state of fusion has from the earliest period of the history of iron down almost to the present day rendered its purification in a fluid state practically and commercially impossible. Hence arise all those imperfections to which bar iron is subject, every small piece consisting of numerous granules partially separated from each other by scoria, and every large mass being produced only by piling together small bars, with the inevitable result of increasing the former imperfections; for no two pieces of iron can be brought to a welding heat without becoming coated with oxide, and when this coating is rendered fluid by welding sand a fluid silicate of the oxide of iron is formed, covering the entire surface to be united. The heavy blows of the hammer or the pressure of the rolls may and do extrude the greater portion of this fluid extraneous matter, but it is never wholly removed from between the welded surfaces, and hence a portion of the cohesive force of the metal is lost at every such junction. When a bar of iron is nicked on one side and bent, the rending open of the pile clearly shows this want of perfect cohesion. Nor is this the only difficulty to be encountered; for in the production of large masses of wrought iron it is necessary to raise the temperature nearly to the fusing point, in order to render each additional piece sufficiently soft and plastic to become united to the bloom: this softening of the iron induces a molecular change in the structure of the metal; its natural tendency to crystallise is so powerfully assisted by the long continuance of the high temperature that its whole structure undergoes a change; large and well defined crystals are formed almost independent of each other, and cohering so feebly to the other contiguous crystals as in some cases to separate with as little force as would overcome the cohesion of ordinary cast iron. In the substitution of cast steel for malleable iron, both these sources of difficulty are escaped: for the mass whether of 1 ton or 20 tons weight may be formed in a fluid state into a single block, wholly free from admixture of scoria, while

it is perfectly and equally coherent at every part; and the forging of such a solid block of metal into shape is only the work of a few hours, and as there is no welding of separate pieces it may be worked under the hammer at a temperature at which no molecular change will take place, the metal being far below its fusing point and much too solid to undergo that destructive crystallisation so common in large masses of wrought iron. Thus the difficulties and uncertainty attending the production of all large masses of wrought iron are wholly avoided in producing equally large masses of cast steel.

But however desirable in the abstract it may be to employ cast steel as a substitute for malleable iron for engineering purposes, it must not be forgotten that there are several important conditions indispensable to its general use. Firstly, the steel must be able to bear a good white heat without falling to pieces under the hammer; otherwise the process of shaping it will not only be expensive, but the partly finished forging may be spoiled at any moment by being overheated. Secondly, the steel should be of such a tough character as to admit of being twisted or bent into almost any form in its cold state before fracture takes place, whether the force be applied as a gradual strain or by a sudden impact. Thirdly, it should have a tensile strength at least 50 per cent. greater than that of the best marks of English iron. Fourthly, it must especially be soft enough to turn well in the lathe, to bore easily, and to yield readily to the file and chisel, so as not to enhance its original cost by the difficulty of working it into the requisite forms. The last is both commercially and practically an important condition, and one which will in future greatly determine the extent of its use. Steel to the engineer has hitherto stood in much the same relation as granite to the builder: the superior hardness, beauty of polish, and durability of granite as compared with other building stone are universally acknowledged, nature has provided it in great profusion, and it has only to be lifted from the earth and made use of; but the practical man has found that to drill a hole in granite for blasting takes days of labour to accomplish, that the stone blunts all the chisels, defies the saw, and is faced only at a great cost; hence the builder goes on using an inferior soft stone over which the tools have perfect command. The

problem to be solved therefore is how to produce cast steel that will take any form in the mould or under the hammer, that will yield quickly and readily to all the present cutting and shaping machines, and will retain all the toughness of the best iron with a much greater tensile strength, and all the clearness of surface, beauty of finish, and durability that so eminently distinguish the harder and more refractory qualities of the steel in common use.

These desirable objects are believed by the author to be fully accomplished by his process of converting crude pig iron into cast steel at a single operation, forming the subject of the present paper. This process has now been in daily operation in Sheffield for the last two years. The apparatus by which it is effected is shown in Plates 30 to 33, which represent the arrangement at Messrs. John Brown and Co.'s, Atlas Steel Works, Sheffield: Fig. 1, Plate 30, is a side elevation, and Figs. 3 and 4, Plate 31, a front elevation and plan.

The crude pig iron chiefly used in this process has been the hot-blast hæmatite pig smelted with coke, which is melted in a reverberatory furnace adjoining, and is then run into the converting vessel A, Figs. 1 and 3, Plates 30 and 31, in which its conversion into steel is to be effected. The converting vessel is shown enlarged in section in Fig. 5, Plate 32, which represents its position in filling, the melted pig iron being run into it by the spout B direct from the furnace. It is made of stout boiler plate and lined with a powdered silicious stone found in the neighbourhood of Sheffield below the coal and known as "ganister." The rapid destruction of the lining of the converting vessel was one of the great difficulties met with in the early stages of the invention: the excessive temperature generated in the vessel together with the solvent action of the fluid slags was found to dissolve the best firebrick so rapidly that sometimes as much as 2 inches thickness would be lost from the lining of the vessel during the 30 minutes required to convert a single charge of iron into steel. The ganister now used however is not only much cheaper than fire-bricks, costing only about 11*s*. per ton in the powdered state, but it is also very durable: a portion of the lining of the vessel is shown which has stood 96 consecutive conversions before its removal. The converting

vessel A is mounted on bearings which rest on stout iron standards CC, Figs. 3 and 4, and by means of the gearing and handle D it may be turned into any required position. There is an opening at the top for filling and pouring out the metal; and at the bottom of the vessel are inserted seven fireclay tuyeres, Fig. 9, Plate 33, each having seven holes, as shown enlarged in the longitudinal section and plan, Figs. 10 and 11. The blast from the engine is conveyed through one of the bearings E of the vessel, Fig. 3, Plate 31, into the tuyere box F, and enters the tuyeres at a pressure of about 14 lbs. per square inch, which is more than sufficient to prevent the fluid metal from entering the tuyeres.

Before commencing with the first charge of metal, the interior of the converting vessel is thoroughly heated by coke, with a blast through the tuyeres to urge the fire; when sufficiently heated it is turned upside down and all the unburnt coke falls out. The vessel is then turned into the position shown in Fig. 5, Plate 32, and the melted pig iron is run in from the furnace by the spout B, the vessel being kept in such a position during the time it is being filled that the holes of the tuyeres are above the surface of the metal. When the proper charge of iron has been run in, the blast is turned on and the vessel quickly moved up into the position shown in Fig. 6. The blast now rushes upwards into the fluid metal from each of the 49 holes of the tuyeres, producing a most violent agitation of the whole mass. The silicium always present in greater or less quantities in pig iron is first attacked, and unites readily with the oxygen of the air, producing silicic acid: at the same time a small portion of the iron undergoes oxidation, and hence a fluid silicate of the oxide of iron is formed, a little carbon being simultaneously burnt off. The heat is thus gradually increased until nearly the whole of the silicium is oxidised, which generally takes place in about 12 minutes from the commencement of the process. The carbon of the pig iron now begins to unite more freely with the oxygen of the air, producing at first a small flame, which rapidly increases, and in about 8 minutes from its first appearance a most intense combustion is going on: the metal rises higher and higher in the vessel, sometimes occupying more than double its former space, and in this frothy fluid state it presents an enormous surface to the action

of the air, which unites rapidly with the carbon contained in the crude iron and produces a most intense combustion, the whole mass being in fact a perfect mixture of metal and fire. The carbon is now burnt off so rapidly as to produce a series of harmless explosions, throwing out the fluid slag in great quantities; while the combustion of the gases is so perfect that a voluminous white flame rushes from the mouth of the vessel, illuminating the whole building and indicating to the practised eye the precise condition of the metal inside. The blowing may thus be left off whenever the number of minutes from the commencement and the appearance of the flame indicate the required quality of metal. This is the mode preferred in working the process in Sweden. But at the works in Sheffield it is preferred to continue blowing the metal beyond this stage, until the flame suddenly drops, which it does just on the approach of the metal to the condition of malleable iron: a small measured quantity of charcoal pig iron containing a known proportion of carbon is then added, and thus steel is produced of any desired degree of carburation, the process having occupied about 28 minutes altogether from the commencement. The converting vessel is tipped forwards and the blast shut off for adding this small charge of pig iron, after which the blast is turned on again for a few seconds.

The vessel is then turned into the position shown in Fig. 7, Plate 33, and the fluid steel run into the casting ladle G, which is carried by the hydraulic crane H, being counterbalanced by the weight I on the opposite end of the jib. When all the metal is poured out of the converting vessel, the crane is raised by water pressure and turned round, as shown in Fig. 2, Plate 30, for the purpose of running the steel into the ingot moulds K. Instead of tilting the casting ladle for pouring into the moulds, it is made with a hole in the bottom fitted with a fireclay seating L, Fig. 8, Plate 33, and closed by a conical plug of fireclay M, forming a conical valve. The valve rod N is coated with loam and bent over at the top, and works in guides on the outside of the ladle, as shown in Fig. 7, with a handle O for opening and closing the valve. By thus tapping the metal from below, no scoria or other floating impurities are allowed to run into the mould, and the stream of fluid steel is dropped straight

down the centre of the mould right to the bottom, without coming in contact with the sides of the mould. The moulds are made of a slightly tapered form, as shown in Fig. 8, so that as the ingot contracts in cooling it liberates itself from the mould completely on all sides; and the mould is removed by being lifted off the ingot when sufficiently set. The moulds are arranged in the moulding pit in an arc of the circle described by the casting ladle, as shown in the plan, Fig. 4, Plate 31.

By this process from 1 to 10 tons of crude iron may be converted into cast steel in 30 minutes, without employing any fuel except that required for melting the pig iron and for the preliminary heating of the converting vessel, the process being effected entirely without manipulation. The loss on the weight of crude iron is from 14 to 18 per cent. with English iron worked in small quantities; but the result of working with a purer iron in Sweden has been carefully noted for two consecutive weeks, and the loss on the weight of fluid iron tapped from the blast furnace was ascertained to be only $8\frac{3}{4}$ per cent. The largest sized apparatus at present erected is that in use at the Atlas Steel Works, Sheffield, as shown in the drawings already described, the converting vessel being capable of converting 4 tons at a time, which it converts into cast steel in 28 minutes. In consequence of the increased size of the converting vessel in this case no metal is thrown out during conversion; and the loss of weight has fallen as low as 10 per cent., including the loss in melting the pig iron in the reverberatory furnace.

Specimens of this manufacture as carried on at the author's works in Sheffield are exhibited, consisting of a piece of the pig iron employed, which is No. 1 hot-blast hæmatite made with coke; also a portion of an ingot of very mild cast steel, broken under the hammer to show the purity and soundness of the metal in its cast unhammered state; and an ingot partly forged to show how little work with the hammer will produce a forging from these solid blooms of steel. There are also two pieces of steel of the quality employed for making piston rods, which have been bent cold under a heavy steam hammer to show the toughness of the metal: it requires very

much more force to bend it than would be required to bend wrought iron, but notwithstanding this additional rigidity it yields to any extent without snapping. The tensile strength of this soft and easily wrought metal is as much as 40 tons per square inch, or from 15 to 18 tons greater than that of best Yorkshire iron. In turning, planing, boring, and tapping, it will be found that the uniformity of its quality will be less trying to the cutting tools than the hard reeds and sand cracks met with in the common qualities of malleable iron. The above tensile strength of the piston-rod steel however is by no means the maximum, but on the contrary is nearly the minimum strength of the steel converted by this process; but at the same time it possesses nearly a maximum degree of toughness, for every additional ton in tensile strength obtained by the addition of carbon hardens the steel for working, renders it more difficult to forge, and brings it nearer to that undesirable state when a sudden blow snaps it like a piece of cast iron.

The extreme limits of tensile strength of the converted metal are shown in the following tables, which give the results of many trials made at different times at the Royal Arsenal at Woolwich under the superintendence of Colonel Wilmot:—

BESSEMER STEEL.

Tensile Strength per square inch.

Bessemer Steel.	Various trials.	Mean Tensile Strength.
In the cast unhammered state.	Lbs. 42,780 48,892 57,295 61,667 64,015 72,503 77,808 79,223	63,023 lbs. = 28·13 tons per square inch.
After hammering or rolling.	136,490 145,512 146,676 156,862 158,899 162,970 162,974	152,912 lbs. = 68·26 tons per square inch.

BESSEMER IRON.

Tensile Strength per square inch.

Bessemer Iron.	Various trials.	Mean Tensile Strength.
In the cast unhammered state.	Lbs. 38,197 40,284 41,584 42,908 43,290	41,243 lbs. = 18·41 tons per square inch.
After hammering or rolling.	64,059 65,253 75,598 76,195 82,110	72,643 lbs. = 32·43 tons per square inch.
Flat Ingot rolled into Boiler Plate without piling.	63,591 63,688 72,896 73,103	68,319 lbs. = 30·50 tons per square inch.

From these tables it is seen that, after hammering or rolling, the steel or highly carbonised metal exhibits a mean tensile strength of 68 tons per square inch, but from its hardness and unyielding nature it is totally unfit for many purposes; while the iron or entirely decarbonised metal is so soft and copper-like in its texture as to yield to a mean tensile strain of 32 tons per square inch, a point unnecessarily low except in cases where a metal approaching copper in softness is required. The soft easy-working tough metal of the quality used for piston rods is therefore believed by the author to be the most appropriate material for general purposes, while the hard steels that range up to a tensile strain of 50 or 60 tons per square inch should be avoided as altogether too expensive to work and too dangerous to be employed in any case where sudden strains may be brought upon them.

With reference to the employment of the mild cast steel for constructive purposes, there are few applications of more importance than that which has recently and successfully been made to the construction of steam boilers. The Cornish boiler, as improved by Mr. Adamson of Hyde near Manchester, has a large flue tube constructed

with narrow plates more than 12 feet long, extending round the flue in one length, and flanged at each edge in a manner which, while it adds greatly to the stability of the flue, demands such qualities in the material employed for its manufacture as are completely found only in metal that has undergone fusion and has become perfectly homogeneous throughout. A practical illustration of the excellence of this mode of constructing boilers and the powerful strains which the new steel is capable of sustaining safely is afforded by the steam boilers employed for some time past at Messrs. Platt's works at Oldham, where six of these boilers are in daily use; they are 30 feet long and 6½ feet diameter, and the flue is 4 feet diameter; the plates are $\frac{5}{16}$ inch thick, and the working pressure 100 lbs. per square inch.

The advantages of cast steel are still more marked in the construction of the fireboxes of locomotive engines. The difficulty of flanging and shaping this work in plate iron without splitting the metal at some part is so great as to have rendered the employment of copper necessary hitherto for this purpose; but the shape required can now be obtained with ease and certainty by hammering up a sheet of metal rolled from one of the cast ingots, such as that now exhibited. One of these firebox plates flanged by Mr. Adamson is also shown, and clearly illustrates the facility with which the new metal may under skilful hands be wrought into any required form. The perfect continuity of the material and its entire freedom from joinings or weldings also obviously render it specially suitable for the tube plates of locomotive engines; for however near the holes are made to one another, there is no danger of their having a flaw or other weak place between them. This is exemplified in the piece of plate now exhibited, in which rivet holes have been punched so close as to remove almost all the metal, without splitting the narrow piece still left between the holes. Nor is it in the construction of the boiler alone that the cast steel may be employed with advantage in locomotives: the axles whether plain or cranked, the piston rods and guide bars, and last but not least the wheel tyres, are all exposed to so much abrasion and to such sudden and powerful strains that a tough strong material capable of withstanding this destructive wear and tear is imperatively

demanded for the satisfactory construction and economical working of the engine.

The special aim of the author during the first year of his labours, which throughout the last six years has never been lost sight of, was the production of a malleable metal peculiarly suitable for the manufacture of ordnance. By means of the process that has been described solid blocks of malleable cast steel may be made of any required size from 1 to 20 or 30 tons weight, with a degree of rapidity and cheapness previously unknown. The metal can also with the utmost facility be made of any amount of carburation and tensile strength that may be found most desirable: commencing at the top of the scale with a quality of steel that is too hard to bore and too brittle to use for ordnance, it can with ease and certainty be made to pass from that degree of hardness by almost imperceptible gradations downwards towards malleable iron, becoming at every stage of decarburation more easy to work and more and more tough and pliable, until it becomes at last pure decarbonised iron, possessing a copper-like degree of toughness not found in any iron produced by puddling. Between these extremes of temper the metal most suitable for ordnance must be found; and all qualities are equally cheap and easy of production.

From the practice now acquired in forging cast steel ordnance at the author's works in Sheffield it has been found that the most satisfactory results are obtained with metal of the same soft description as that employed for making piston rods. With this degree of toughness the bursting of the gun becomes almost impossible, its power of resisting a tensile strain being at least 15 tons per square inch greater than that of the best English bar iron. Every gun before leaving the works has a piece cut off the end, which is roughly forged into a bar of 2 inches by 3 inches section, and bent cold under the hammer in order to show the state of the metal after forging. Several test bars cut from the ends of guns recently forged are exhibited.

The power of this metal to resist a sudden and powerful strain is well illustrated by the piece of gun muzzle now shown, which is one of several tubular pieces that were subjected to a sudden crushing

force at the Royal Arsenal, Woolwich, under the direction of Colonel Wilmot; the pieces were laid on the anvil block in a perfectly cold state, and were crushed flat by the falling of the steam hammer, but none of them exhibited any signs of fracture when so tested. Probably the best proof of the power of the metal to resist a sudden violent strain was afforded by some experiments made at Liège by order of the Belgian government, who had one of these guns bored for a 12 lbs. spherical shot of 4⅝ inches diameter, and made so thin as to weigh only 9¼ cwts. This gun was fired with increasing charges of powder and an additional shot after each three discharges, until it reached a maximum of 6⅝ lbs. of powder and eight shots of 12 lbs. each or 96 lbs. of shot, the shots being thus equal to about one tenth of the weight of the gun. It stood this heavy charge twice and then gave way at about 40 inches from the muzzle, probably owing to the jamming of the shots. The employment of guns so excessively light and charges so extremely heavy would of course never be attempted in practice.

Some idea of the facility of this mode of making cast steel ordnance is afforded by the time occupied in the fabrication of the 18 pounder gun now exhibited, which was made in the author's presence for his experiments on gunnery. The melted pig iron was tapped from the reverberatory furnace at 11.20 A.M., and converted into cast steel in 30 minutes; the ingot was cast in an iron mould 16 inches square by 4 feet long, and was forged while still hot from the casting operation. By this mode of treating the ingots their central parts are sufficiently soft to receive the full effect of the hammer. At 7 P.M. the forging was completed and the gun ready for the boring mill.

The erection of the necessary apparatus for the production of steel by this process, on a scale capable of converting from crude iron enough steel to make forty of such gun blocks per day, will not exceed a cost of £5000, including the blast engine; hence the author cannot but feel that his labours in this direction have been crowned with entire success: the great rapidity of production, the cheapness of the material, and its strength and durability, all adapt it for the construction of every species of ordnance.

For the practical engineer enough has already been said to show how important is the application of cast steel to constructive purposes, and how this valuable material may be both cast and forged with such facility and at a cost so moderate as to produce by its superior durability and extreme lightness an economy in its use as compared with iron. The construction of cast steel girders and bridges, and of marine engine shafts, cranks, screw propellers, anchors, and railway wheels, are all deserving of careful attention. The manufacturer of cast steel has only to produce at a moderate cost the various qualities of steel required for constructive purposes to ensure its rapid introduction; for as certainly as the age of iron superseded that of bronze, so will the age of steel succeed that of iron.

Mr. Bessemer exhibited an 18 pounder gun made of the Bessemer steel cast in a single ingot of the required size and subsequently hammered, with a variety of specimens of the metal, broken to show the quality of the fracture; also some piston rods, a boiler plate flanged for a locomotive firebox and a plate bulged in a die without cracking or tearing, a plate of thin metal punched with a number of small holes very close together, and a tube of the metal which had been crushed flat without the surface of the metal cracking. He showed also one of the fireclay tuyeres used for blowing the melted metal in the converting vessel, and specimens of the ganister used for lining the vessel and ladle, both new and after use.

The Chairman enquired whether the steel produced by this method was considered superior in quality and regularity of make as compared with that made by the ordinary process of conversion, apart from the question of cost of manufacture.

Mr. Bessemer said that from all the experience they had had of the steel there was certainly no inferiority in quality when made from the best qualities of iron; no process had yet succeeded in making best steel from very common iron, and all steel makers resorted to

good iron for making the best steel, which he expected would long continue a necessary condition of success. The custom of the Sheffield steel makers was to use none but best Swedish iron or other foreign iron of high character for making all the best cast steel; and the same result was obtained with at least equal success by the new process from the same material. But in addition to this he had also succeeded in producing from lower qualities of English iron a very valuable material having great regularity of make and possessing important advantages in the combination of toughness and strength; while the cost was so much below that of any previous cast steel as to bring it into use in place of wrought iron for many purposes from which steel was entirely excluded hitherto by the high cost. For the best steel he still made use of Swedish pig, as the purest and best iron; but the process had this great advantage over the ordinary method of making steel, that in the latter the steel was produced by converting bars of wrought iron made from the original pig, but in the new process the pig itself from which the bars would have been made was treated direct, thus saving the entire cost and waste of the intermediate process of manufacturing the iron into bars. Hence taking the same brand of pig iron, an equally good quality of steel was obtained at a greatly reduced cost, and with greater uniformity of conversion than was possible by the ordinary process of cementation, since the metal was dealt with in a liquid state, instead of in the form of solid bars which could be acted upon from the outside only. He expected in time to be able to obtain a still better result from the lower qualities of English iron, as there was nothing in the process itself to prevent any description of iron from being converted into the best steel that it was capable of yielding.

In the new process the carbon and silicium of the iron itself were employed as fuel to support the heat for reducing the cast iron, and the intense heat thus obtained together with the intimate mixing of the air blown through the metal while in a fluid state caused the reduction to be much more rapid. Instead of the silicium in the iron requiring 2 or 3 hours to be burnt out, as in the ordinary puddling process, it was now burnt out in only 12 minutes, giving out a great amount of heat by its combustion; and the complete reduction of the

metal occupied less than half an hour, and was accomplished with far greater certainty and completeness, while 3 or 4 tons were acted upon at once, instead of only as many cwts.

For the construction of ordnance an excessive toughness of metal was wanted, and in this respect the new steel had an advantage over ordinary cast steel which rendered it specially suitable for that purpose. Toughness implied a soft and mild quality of steel, but this required a very high temperature for melting, and it was not enough for the metal to be simply fluid, but it must be what the workmen called *well* melted; for if merely brought to a state of fusion and then formed into an ingot it did not work satisfactorily in the subsequent process of forging. In the ordinary process the difficulty of getting the steel sufficiently well melted increased in proportion to the softness or mildness of the metal: hence it sometimes occurred that a manufacturer would not attempt using quite so mild a quality of steel for a large casting; and a little more hardness was allowed, so as to admit of a lower temperature for melting, by increasing the extent of carbonisation in order to render the operation of casting less troublesome and expensive. But in the new process any degree of softness could be allowed, and the reduction in the converting vessel could be carried on till the metal even approached malleable iron, without adding at all to the trouble or expense of casting. When the reduction was carried to the extreme extent, the metal had a remarkably tough and soft quality, like copper, and seemed likely to prove a very valuable material for many purposes where these properties were of importance. The most satisfactory material for making guns he believed would be a perfectly homogeneous metal, having somewhat of the character of steel, but closely approaching malleable iron, of a tough quality and without any weldings; and this mode of casting the gun in a single large ingot of the required size, as shown in the specimen exhibited, precluded the possibility of working up improper material into the gun, and ensured its possessing the same strength in all parts.

The CHAIRMAN enquired whether the plates made from the new steel were much used at present, such as the specimens of flanged boiler plates that were exhibited.

Mr. Bessemer replied that the plates were now extensively in use and the steel proved a very good material for boiler plates, as it was very reliable in working from being of such a uniform texture throughout.

Mr. D. Adamson said he had already used 200 tons of boiler plates made from the new steel and was about to procure a further supply of 70 tons ; he found the metal of excellent quality and regular character throughout, and it was an admirable material for working. The flanged firebox plate now shown was a duplicate of a number that he had used in the manufacture of boilers for very high pressure with most satisfactory results ; the metal flanged beautifully and was like copper in this respect, but with the advantage that it was not so liable as copper to be damaged by heating. He could fully confirm the statements given as to its strength, having tested it very severely : as a precaution every plate had been ordered with 1 inch margin all round, which was then sheared off and bent double as a test of the quality of the plate ; it was found to stand this test well, and bent double like the specimens exhibited without cracking at any part of the surface. The price of the plates was an important consideration in making steel boilers for the advanced pressures now coming into use : the boilers that he had made with the new plates cost about one third more than with best iron plates, but then the joints were all double rivetted, and a large portion of the rivet holes drilled instead of punched, to obtain greater accuracy of work and avoid straining the metal, the boilers being intended for working at high pressures of 100 lbs. per square inch and upwards. The increased cost was therefore mainly occasioned by the superior workmanship; but it was well worth while to bestow a higher class of labour upon the higher class of metal here produced, whereby a far more valuable result was obtained. The durability of these steel plates in the fire flues of steam boilers with hard firing had been well tested in some boilers he had made for Messrs. Platt at Oldham, the results of which had been thoroughly satisfactory.

The only difficulty he had met with in working the new steel arose from unequal expansion of the plates or bars, when they had left the rolls at different temperatures. When a plate that had left the rolls

at a low temperature was rivetted to one that had not been rolled so cold, the two did not expand equally when exposed to a considerable heat in the working of the boiler, and there was a constant strain on the joint; this difficulty gave some trouble at first, but was now got over by having all the plates and bars annealed for some time, after leaving the rolls, and they were then thoroughly soft and uniform in quality, so that they could be worked in any way with the greatest facility.

In resisting the strain of compression to which the internal flues of boilers were exposed, there was no doubt the steel plates would be much stronger and better than ordinary boiler plates; he had not however made much diminution of thickness in the metal, preferring to take full advantage of the increased strength in that part of the boiler; but it was very desirable that experiments should be made to determine the actual strength of the new plates in such positions. Whether the plates would withstand a tensile strain equally well in all directions he thought should also be tried; as in the case of the attachment of the domes of steam boilers, where the bottom of the dome was flanged out for rivetting to the boiler, and the metal at that part was subjected to two strains at right angles to each other, one of them tending to tear the plate asunder from the edge inwards. It was therefore important to try whether the plates would stand such a compound strain as well as they resisted the single bursting strain in the barrel of a boiler; for if this were the case, they might be depended upon with equal security for all situations. They were essentially superior he considered to any plates manufactured from piled iron, as they were entirely free from lamination and were truly homogeneous throughout.

Mr. W. Richardson said he had made trial of the Bessemer steel plates for some time in boilers at Messrs. Platt's works at Oldham, where some years ago a higher pressure of steam was adopted than was then usual. At that time they frequently found distress at the joints of the boilers, and had then adopted double rivetting; and the firebox plates were frequently blistered, though of a good make of iron. Subsequently three boilers were made of plates of homogeneous metal, which had now been at work three years; but since the

Bessemer steel had been produced at a cheaper rate and equally reliable in strength and quality they had used it extensively, and had now six boilers constructed of the new plates. They had now no more trouble from blistered plates and strained joints, while a great saving was effected in thickness of metal, requiring less fuel to produce the same heating power: the steel plates were only $\frac{5}{16}$ inch thick for the same strength as the former $\frac{9}{16}$ inch iron plates, so that there was only $\frac{5}{8}$ inch thickness at the lap of the joints instead of $1\frac{1}{8}$ inch, or only $\frac{1}{16}$ inch greater thickness at the joints of the steel plates than with the single thickness of ordinary iron plate. They had had only two years' experience of the new plates at present, but during that time the results had proved thoroughly satisfactory.

Mr. B. Fothergill asked whether the Bessemer plates showed any liability to become corroded along the line of the joints where the plates overlapped, as was frequently the case in wrought iron boilers, which were liable to become cracked at that part to a considerable depth in the thickness of the metal, in consequence of the plates trying to pull themselves straight on both sides the joint when the pressure was on, and recovering themselves again each time the steam was down.

Mr. W. Richardson said he had not observed any corrosion yet in the steel plates, but the boilers had not been long enough at work to prove whether they would remain free from it. Their own practice was to strip all the boilers once a year for a thorough examination, and clean out all the scale and dirt, and then put on a coat of linseed oil all over, which was very effective in preserving the plates from corrosion. The boilers were $6\frac{1}{2}$ feet diameter and 30 feet long, with one fire flue 3 feet 10 inches diameter, and worked at a pressure of 85 lbs. per square inch.

Mr. H. W. Harman enquired whether in the process of manufacturing the steel any other means had been arrived at of ascertaining the quality of the metal in the converting vessel and its degree of preparation, beyond merely observing the appearance of the flame from the mouth of the vessel and its cessation when the conversion was completed: and whether the indications were sufficiently accurate to ensure the same quality of metal being produced at all times.

Mr. Bessemer replied that the new process afforded great facility for judging of the quality of metal in the converting vessel, more so than any other process for manufacturing steel. For the quality was determined not only by the judgment of the workmen, who after some practice could tell with great accuracy from the changes in the flame; but the time of blowing into the converting vessel was definitely measured according to the weight of metal it contained, and the small quantity of pig iron added in the last stage of the process was also accurately weighed, thus determining the exact quantity of carbon put into the metal to convert it back from wrought iron into steel, which had not been so definitely accomplished in any previous method of conversion. As the process was entirely mechanical and independent of the workmen, the result could be relied on with great certainty; it was thus very different from the ordinary case of puddling in the manufacture of wrought iron, where the quality of iron produced depended altogether on the judgment and skill of the workman. The sudden drop in the flame when the decarbonisation of the iron was completed could be observed with great readiness; and the measured weight of melted pig iron containing a known proportion of carbon was then added at once, combining with the metal while in a melted state, and producing a definite quality of steel. With 20 cwts. of metal in the crucible 120 lbs. of pig iron was the usual quantity added, which was increased up to 130 or 140 lbs. for making harder qualities of steel. The uniform and soft quality of the steel that had been rolled into boiler plates was shown by the severe manner in which it had been tested, by cutting off a strip from every plate for trying; but a further test was afforded by the subsequent working of the plate, for if it were brittle and irregular, hard in some places and soft in others, that would inevitably be found out in punching and flanging. The use of the large quantity of the plates already employed at the works where they were so tested was a satisfactory proof of the uniform quality of steel obtained by the new process.

With regard to corrosion of the steel plates in boilers, in no case was steel dissolved by acid so much as wrought iron. The new steel especially, being a perfectly homogeneous material united closely

at all parts and entirely free from lamination of structure, presented no inequalities of texture and no openings for the corrosion to begin eating its way in: whereas iron had innumerable small fissures in its substance, and if the surface of any malleable iron were filed or planed smooth, and then covered with a dilute acid for a few minutes, on wiping off the acid an etching was left all over the surface from the irregularity of the material, capable even of being printed from; but on the steel plates no such effect was produced by the acid. This showed how wrought iron became corroded, by the corrosion commencing in the minute interstices at its surface and gradually extending itself through them into the body of the iron. The bars of wrought iron pallisades were known to become corroded at the bottom in this way; and even cast iron suffered in a similar manner, though in a much smaller degree.

Mr. H. Maudslay observed that an interesting point had been elicited in the discussion, with regard to the different expansion of the new steel plates when they had left the rolls at different temperatures. He thought that further information and experiments on the subject were highly desirable, and as to whether the remark applied to the new steel alone or to iron generally.

Mr. D. Adamson had tried three sets of bars, of Bessemer steel, puddled steel, and scrap iron, that had left the rolls at different temperatures, the bars all 10 feet long and each set welded together at one end: after heating them to a moderate red heat there was found to be as much as ⅛ inch difference in length among the rods of the same material, and he therefore came to the conclusion that it was not advisable to unite together in the same work plates that had left the rolls at different temperatures, as the coldest rolled plates expanded more on being reheated the first time. However on reheating the same rods, not one tenth of the difference first observed took place; and the objection at first experienced was now obviated by annealing all the plates and bars of Bessemer steel for some hours after they had left the rolls.

Mr. H. Maudslay thought the effect of the second heating was very remarkable, in causing the difference of expansion to disappear: it showed the necessity of having all bars or plates of the new steel

left in a known state after rolling, by annealing them as described, in order to avoid the inconvenience of variable expansion.

The CHAIRMAN said the specimens of metal exhibited and the results obtained were certainly highly satisfactory, and the new process appeared one of great scientific beauty. If the new steel could indeed be produced regularly of the quality described and in large masses, it was the very material that had long been wanted by engineers. He only wondered it was not more in use at present, if these results were really permanently secured and could be fully relied upon in regular manufacture.

The use of steel plates for boilers had been tried for some time, but he believed the objection to them had been want of uniformity in temper and quality, so that they could not be used with safety. But if the new process was so successful in excluding all liability to variation of quality and in producing a really homogeneous steel, an equal strength in all parts of the plates might be relied on; and he was glad to hear now of their being practically applied for boiler purposes.

There was not so much difficulty however in the case of plates worked down under rolls in obtaining sufficient strength and soundness of work; the great difficulty was with a great thickness of metal, in ensuring soundness in the interior of large castings and equal density and toughness in all parts. The new process did not appear exempt from this difficulty, which applied to a homogeneous metal when worked in large masses almost as much as to ordinary iron; and there seemed to be no short road to making large forgings, but they must still go through a sufficient amount of heavy hammering to ensure the necessary solidity. For such work one essential he was satisfied was a massive forge hammer, greatly enlarged beyond those at present in general use. Mr. Krupp of Essen in Prussia, who had been the pioneer in the treatment of cast steel in large masses, was now actually erecting an enormous hammer of 40 tons weight; and this must be in order to get over some objection experienced where the steel was not sufficiently hammered. In his own experiments on the manufacture of ordnance he had tried all sorts of steel, excepting the Bessemer steel, when the greatest pains had been taken by the makers

to overcome the difficulties and produce a thoroughly sound material. But nearly all the trouble in connexion with guns had arisen from using steel, and he had not been able to get any steel to stand the action of long continued firing. In a bar where the thickness was small it had tenacity enough, but in a block it was different, the liability to fracture displaying itself as soon as any considerable thickness was attempted. It was quite possible however that if well worked under a large hammer while hot, a large mass of steel might be made to have all the good qualities that it possessed when worked on a small scale. He enquired whether any gun of large mass had been attempted with the new steel.

Mr. BESSEMER replied that he had not yet made any guns larger than the 18 pounder now exhibited, excepting a few 24 pounders; but the 12 pounder spherical-shot gun of the new steel, tried in Belgium, was bored to 4⅝ inches diameter, which was the same diameter of bore as that of the Armstrong 40 pounder guns, while the weight was only 9¼ cwts. as compared with 34 cwts. the weight of the old cast iron guns of the same bore, and 32 cwts. the weight of the Armstrong 40 pounder. The great strength obtained with so light a gun was well shown by the experiments in Belgium with the 12 pounder gun of the new steel, the metal of which was only [illegible] inch thick at the muzzle and 2⅜ inches at the breech; but it stood the test of firing with continually increasing charges, from 2 shots of 12 lbs. each and 2¼ lbs. of powder, up to 8 shots or 96 lbs. of shot and 6¼ lbs. of powder. At the third firing of this heavy charge the gun parted at about the middle of its length, where the thickness of metal was 1⅞ inch, probably on account of the shot slightly overriding one another and getting jammed at the muzzle; at the same time the excessive recoil of the gun under so large a charge tended to snap the metal asunder, but there was no rupture of the gun longitudinally.

He fully acknowledged the great labours of Mr. Krupp of Essen, who was undoubtedly the leader in the production of large masses of cast steel; but he thought the large 40 ton steam hammer that had been mentioned was intended only for the very largest work, such as marine shafts of 20 or 30 tons weight, and the general run of work would not require hammers larger than the ordinary size at present used.

The great advantage of using cast steel for making large pieces of work was that there were no welds in the mass of metal, but it was cast at once of the full size required and of nearly homogeneous quality throughout, and was then beaten out under the hammer into the proper shape, having been cast originally in the form most suitable for producing the finished forging. The old practice with cast steel was to let the ingot get cold after casting, and it was left to lie rusting before being worked into shape, under a mistaken notion of its becoming milder by exposure in the air. But the gun now exhibited of the new steel was never allowed to get cold from the time of casting till the forging was finished. The metal was poured from the ladle into a cold iron mould, forming an ingot 16 inches square and 40 inches long; the external surface got cooled directly, but the inside remained still so soft that a rod could be run down the centre when the outside was cold enough to be solid. After remaining 20 minutes in the cold mould it was then too cold outside for working under the hammer, though still very hot inside; and it was therefore put in a furnace for a short time and reheated on the outside till it was nearly equally hot all through, leaving still however an excess of heat in the centre. The inside was protected from damage in the reheating by being completely encased in the cooler exterior portion, and got no injury, not being exposed to the air; but when put under the hammer the centre was so much softer than the outside that the large masses thus cast in the mould could be readily hammered through right to the centre. The whole forging was thus completed at the only time when the mass was in the very best condition for working, for in no subsequent reheating could it ever be got hotter in the centre than on the outside, nor even so hot; but in ordinary forging, the entire heating being done from the outside which was exposed to the atmosphere, the metal was unavoidably overheated on the outside and more or less burnt, whilst the interior was still not sufficiently heated for the blow to penetrate the mass fully.

Toughness and tensile strength did not require a laminated structure of the metal, but depended on softness of quality and on the amount of hammering it had undergone. In trials he had made of the effect of hammering on the new steel, an ingot just cast,

3 inches square, sustained a tensile strain of 21 tons per square inch, but after being reduced ¼ inch each way by hammering it stood 57 tons per square inch; on further drawing it down however to a bar ¾ inch square, no more practical gain in strength was obtained, showing that a certain moderate amount of hammering, if properly done, produced the full effect that was required in condensing the substance of the metal. The object of the hammer was not to weld the steel together as in hammering a bloom of wrought iron, but merely to compress the particles together, and the crystals then united most readily; nor was the hammering needed to develop a fibrous character in the metal, for fibre had nothing to do with the strength of steel, but an ingot simply condensed by a small amount of hammering after casting possessed the same strength as if drawn down into a bar under the hammer.

Mr. R. Longsdon thought the circumstance that the new steel had not yet been brought into more extensive use could not be taken as an argument against its value; for the difficulties of introducing any new material were so great, and in the ordnance experiments it was admitted the steel had not even had a trial at present. That more had not already been done was no reason why more should not yet be done, when the new steel had become better known. Hitherto it had been used mainly for comparatively small articles, but these had proved thoroughly successful, and he thought that in large forgings there was no doubt of the same success being obtained when the steel was sufficiently hammered after casting.

The Chairman gathered from the statements made about the new steel that it did not differ materially from cast steel obtained by the ordinary process, except in being much less expensive and more truly a homogeneous and pure metal. From his own experience of ordinary cast steel he was not able to speak favourably of it for large masses of metal such as guns: but he was sure all would be glad if the difficulties connected with it could be overcome, and all would most heartily wish success to Mr. Bessemer's ingenuity and perseverance.

He proposed a vote of thanks to Mr. Bessemer for his highly interesting paper, which was passed.

The following paper was then read:—

ON THE STRENGTH OF STEEL CONTAINING DIFFERENT PROPORTIONS OF CARBON.

By Mr. T. EDWARD VICKERS, of Sheffield.

Three most important materials of British manufacture—wrought iron, steel, and cast iron—are combinations of iron with a smaller or larger amount of carbon. Wrought iron contains from about $\frac{1}{8}$ to $\frac{1}{5}$ per cent. of carbon, cast steel about $\frac{3}{8}$ to 2 per cent., and cast iron from $2\frac{1}{2}$ to 7 per cent. The great variety of opinions that have been expressed respecting the strength of steel when containing different proportions of carbon led the writer to make a number of tests upon this point, the results of which are given in the present paper with the conclusions derived from them.

The degree of carbonisation in the several varieties of steel tested in the experiments ranged from about $\frac{1}{3}$ per cent. of carbon to $1\frac{1}{4}$ per cent.; the softest or least carbonised steel containing $\frac{1}{3}$ per cent. of carbon was called No. 2, and the hardest or most highly carbonised containing $1\frac{1}{4}$ per cent. of carbon No. 20, the intermediate numbers representing intermediate degrees of carbonisation. The tests to which the steel was subjected consisted in ascertaining its tensile strength, by means of bars of the steel broken by direct tension; and also its transverse strength, by means of axles made of the steel which were broken by the blows of a heavy ram.

Tensile Strength.—The tensile strength of the several varieties of steel was tested by the simple lever machine shown in Plate 34, in which the leverage is 220 inches to 11 inches, or 20 to 1, Fig. 1, so that each cwt. added in the scale at the long end of the lever produces a tension of 1 ton on the test bar at the other end of the lever. The test bars A, Figs. 2, 3, and 4, are $21\frac{1}{2}$ inches long, with 14 inches of their length turned down to a uniform diameter of 1 inch. For

facility of fixing the bars in the testing machine and removing them when broken, the ends are made wedge-shaped, and the lower end is held in a conical socket in the holding-down block B, into which it is inserted through the longitudinal slot shown in the plan, Fig. 6; the bar is then turned half round, and the upper end slipped into the wedge-shaped holder C at top, whereby the bar is securely held during the testing. The following Table I gives the results of the trials, showing the breaking strain reduced to tons per square inch, together with the amount of elongation produced in the bars :—

TABLE I.

Tensile Strength of Steel containing different proportions of Carbon.

Description of Steel.	Proportion of Carbon (approximate.)*	Breaking Strain per square inch.	Elongation.
	Per cent.	Tons.	Inch.
No. 2	0·38	30·4	1·37
No. 4	0·43	34·0	1·37
No. 5	0·48	37·5	1·25
No. 6	0·53	42·5	1·12
No. 7	0·58	41·5 **	0·81
No. 8	0·63	45·0	1·00
No. 10	0·74	45·5	0·69
No. 12	0·84	55·0	1·12
No. 15	1·00	60·0	1·00
No. 20	1·25	69·0	0·62

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

** There was a flaw in this test bar, which will account for its breaking at a lower strain than the preceding No.

The elongation was measured after each addition of load in the scale at the long end of the lever; and that given in the table is the final amount of elongation, previous to adding the last cwt. in the scale which caused the breakage.

The table shows that the tensile strength of the steel is increased by the addition of carbon, until it is combined with about 1¼ per cent. of carbon, when it sustains about 69 tons per square inch. But

beyond this degree of carbonisation the steel becomes gradually weaker, until it reaches the form of cast iron, which sustains a tensile strain of only about 6 or 6½ tons per square inch. When the test bar is turned down at one point only, instead of through a considerable length, the result obtained has been found to be different: for a bar of steel turned down to ¾ inch diameter at one point only, as shown at D in Fig. 5, did not break till the strain reached 79½ tons per square inch; whereas a bar of the same steel turned down to 1 inch diameter for 14 inches of its length broke with a tension of 60 tons per square inch.

Transverse Strength.—For testing the transverse strength of the several varieties of steel, axles were made of the steel in the various degrees of carbonisation, which were subjected to the blows of a heavy ram until broken. The axles were all turned to 3·94 inches diameter at the centre and 4·25 inches at the ends, and were supported on bearings 3 feet apart, as shown in Figs. 7 and 10, Plate 35; they were reversed at intervals when considerably bent by the blows of the ram, as shown by Figs. 8 and 9. The ram weighed 1547 lbs. or nearly 14 cwts., and was dropped on the centre of the axle from a height commencing at 1 foot and increasing at each successive blow up to 36 feet fall, unless the axle was broken at a previous blow.

Table II gives the detail of the experiment on an axle of No. 4 steel, containing about $\frac{4}{10}$ per cent. of carbon; showing that it stood 5 blows of the ram falling from 36 feet height before breaking, after 12 blows from lower heights of fall, and the sum of all the deflections produced by the blows amounted to 56 inches.

TABLE II.

Detail of Experiment on Transverse Strength of Axle made of No. 4 Steel.

No. of Blow.	Height of Fall.	Deflection.		
		Before blow.	After blow.	Effect of blow.
	Feet.	Inches.	Inches.	Inches.
1	1	— 0·00	⌣ 0·19	0·19
2	2	⌣ 0·19	⌣ 0·53	0·34
3	3	⌣ 0·53	⌣ 1·12	0·59
4	4	⌢ 1·12	— 0·00	1·12
5	5	— 0·00	⌣ 1·19	1·19
6	7½	⌣ 1·19	⌣ 2·19	1·00
7	10	⌢ 2·19	— 0·00	2·19
8	12½	— 0·00	⌣ 2·19	2·19
9	15	⌢ 2·19	⌣ 0·75	2·94
10	20	⌢ 0·75	⌣ 3·00	3·75
11	25	⌢ 3·00	⌣ 1·50	4·50
12	30	⌢ 1·50	⌣ 3·81	5·31
13	36	⌢ 3·81	⌣ 2·37	6·19
14	36	⌢ 2·37	⌣ 3·75	6·12
15	36	⌢ 3·75	⌣ 2·31	6·06
16	36	⌢ 2·31	⌣ 3·88	6·19
17	36	⌢ 3·88	⌣ 2·25	6·13
18	36	⌢ 2·25	broken	...
			Sum of Deflections	56·00

Table III gives the general results of the series of experiments made in a similar manner to the above, with axles of the several varieties of steel; showing the total number of blows required to break each axle, the number that it sustained with 36 feet fall of the ram before breaking, and the sum of all the deflections produced. Three wrought iron axles were also tried in the same way, one of the best faggotted axles that could be procured, and two scrap iron axles.

TABLE III.

Transverse Strength of Axles made of Steel containing different proportions of Carbon.

Material of Axle.	Proportion of Carbon (approximate.)*	Total number of Blows.	Height of Fall in last blow.	Number of blows sustained from 36 feet height.	Sum of Deflections.
	Per cent.		Feet.		Inches.
Steel No. 2	0·33	17	36	4	58·81
No. 4	0·43	18	36	5	56·00
No. 5	0·48	17	36	5	53·56
No. 6	0·53	15	36	2	35·06
No. 7	0·58	16	36	3	33·81
No. 8	0·63	18	36	5	46·00
No. 10	0·74	16	36	3	40·31
No. 12	0·84	10	20	0	8·56
No. 15	1·00	8	12½	0	4·31
No. 20	1·25	10	20	0	6·94
Best wrought iron	...	13 **	36	0	31·19
Scrap iron	...	5	5	0	2·00
Scrap iron	...	5 †	5	0	3·69

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

** Cracks began to show at the tenth blow, with 20 feet height of fall, and increased at each subsequent blow.

† Two large cracks opened at the fifth blow, therefore it was considered practically broken.

From these experiments it appears that, for bearing sudden and heavy blows, without regard to rigidity, the metal cannot contain too little carbon, provided it be pure and there be perfect cohesion of the particles. These qualities however cannot exist to the required degree in wrought iron or puddled steel, as shown by the experiment with the wrought iron axle in the above table; and are to be found only in cast steel, which must contain at least enough carbon to render it sufficiently fluid in melting. The steel melting process alone can effectually rid the metal of the impurities that were contained in the iron from which it is made.

There is nothing more deleterious to iron or steel than overheating or too many heatings, and the writer believes that all welding affects the quality of the metal more or less injuriously. Cast steel has the great advantage of being less liable than any other metal in general use to become crystallised by vibration. It has already a natural crystal, and the result of the writer's experience is that its crystal can be changed into a weak form only by being overheated. Cast steel and Swedish wrought iron have been placed where they were subjected equally to continual blows, concussions, and vibrations; and the cast steel was found to stand for a long period without change of crystal, where the Swedish iron broke very soon, showing great changes in its form of crystallisation.

For most mechanical purposes the best material in practice is one that combines the power of resisting a tolerably high tensile as well as transverse strain; one that will bear a tension of about 45 to 50 tons per square inch will generally be quite strong enough, and will be below the point at which brittleness from too great rigidity begins. The following Table IV gives a comparison of the preceding Tables I and III, and shows that such a material is found in the steel Nos. 8 to 10, containing about $\frac{5}{8}$ to $\frac{3}{4}$ per cent. of carbon. There are of course purposes where a specially ductile or specially rigid material should be employed, but the latter should be used only in cases where it is not liable to be subjected to sudden concussions.

TABLE IV.

Transverse and Tensile Strength of Steel containing different proportions of Carbon.

Description of Steel.	Proportion of Carbon (approximate.)*	TRANSVERSE. Sum of Deflections.	TENSILE. Breaking Strain per square inch.	Elongation.
	Per cent.	Inches.	Tons.	Inch.
No. 2	0·33	58·81	30·4	1·37
No. 4	0·43	56·00	34·0	1·37
No. 5	0·48	53·56	37·5	1·25
No. 6	0·53	35·06	42·5	1·12
No. 7	0·58	38·81	41·5	0·81
No. 8	0·63	46·00	45·0	1·00
No. 10	0·74	40·31	45·5	0·69
No. 12	0·84	8·56	55·0	1·12
No. 15	1·00	4·31	60·0	1·00
No. 20	1·25	6·94	69·0	0·62

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

The superior strength of cast steel cannot be better illustrated than by stating that castings of steel, without hammering, rolling, or other means of mechanical compression, show a very high degree of strength and tenacity, far above that of castings of any other metal in practical use. Advantage is taken of this property to make bells of cast steel, one third lighter than bronze bells of the same diameter; and these lighter steel bells still bear double the breaking strain of the bronze ones. Another feature in the superior strength of castings in steel is that they are not so liable as other metals to break when subjected to concussions during intense frost, as proved by the fact that the cast steel bells have been rung without the least injury in Russia and in Canada, when the thermometer ranged lower than 20° below zero Fahr.; while the heavier and thicker bronze bells could not be rung in the same temperature without cracking.

The same properties have also led to the manufacture of cast steel disc wheels with tyres in one solid body, for railway carriages and engines. One of these disc wheels was tested in the manner shown

in Fig. 11, Plate 35: the wheel was put upon an axle fixed firmly in bearings at each end, and the ball E weighing 830 lbs. or nearly 7½ cwts., suspended by an iron rod 24 feet long, as shown in the drawing, was drawn back and let fall so as to strike the wheel on the outside of the rim or tyre. The wheel was struck nine blows increasing from 1 foot to 14 feet in vertical height of fall, after which the axle was so much bent that the ball could not strike the wheel. The axle was then straightened by striking the wheel on the opposite side, and was propped up to prevent bending again; and two more blows were struck from the height of 15 and 16 feet, without causing any damage to the wheel.

The results of all the experiments that have been described show that cast steel, which even to the present time is considered by many a brittle material, fit only for a cutting instrument, is in fact a metal having not only all the good and desirable properties of wrought iron in a higher degree, but at the same time freedom from most of the objectionable properties of the latter, and admitting of being employed for every mechanical purpose where great ductility, tenacity, and transverse strength, are required.

In reference to the specific gravity of steel as affected by the proportion of carbon it contains, chemists and scientific writers have generally given the specific gravity of steel as about 7·850 and of wrought iron about 7·650, that of water being 1·000; which leads to the inference that the addition of carbon to iron has the effect of increasing its density, and such is the general opinion at present. The contrary however has been found by the writer to be the fact, namely that pure iron decreases in density the more carbon there is combined with it. The low specific gravity of wrought iron above stated must therefore have been obtained from common English merchant iron, a piece of which gave a specific gravity of 7·644, which very nearly agrees with that above mentioned; and must be owing to the impurities contained in the iron. The specific gravity of one of the purest and softest Swedish irons is 7·894; and that of the iron from which the steel was made for all the experiments that have been described above is about 7·860. Table V gives the specific

gravities as ascertained by experiment of the successive gradations of steel, from No. 2 containing about ⅓ per cent. of carbon up to No. 20 containing about 1¼ per cent., the results having been all obtained with pieces of metal of considerable size, varying from 2¾ to 4⅓ oz. in weight.

TABLE V.

Specific Gravity of Steel containing different proportions of Carbon.

Description of Steel.	Proportion of Carbon (approximate.)*	Specific Gravity.
	Per cent.	
Swedish Iron, pure and soft	...	7·894
Iron from which the Steel was made	...	7·860
Steel No. 2	0·33	7·871
No. 4	0·43	7·867
No. 5	0·48	7·855
No. 6	0·53	7·855
No. 7	0·58	7·852
No. 8	0·63	7·848
No. 10	0·74	7·847
No. 12	0·84	7·840
No. 15	1·00	7·836
No. 20	1·25	7·823
Puddled Steel, for melting purposes	...	7·824
Cast Iron, mean of best authorities	2¼ to 7	7·204

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

The specific gravities of the steel No. 2 and No. 4 are here seen to be greater than that of the original iron; but this may be attributed to the iron being freed from impurities in the melting. The conclusion therefore derived from the above figures is that every successive addition of carbon to pure iron renders the metal less dense or diminishes its specific gravity.

Mr. VICKERS exhibited a number of strips of steel plate $\frac{5}{16}$ inch thick, which had been tested to show how far they could each be bent before cracking, when containing different proportions of carbon. Also a large cast steel pinion, and one of the steel axles that had been tested. After testing the axles, he had rolled down the broken pieces into plates $\frac{5}{16}$ inch thick, and tried them by bending, as shown by the other specimens exhibited. The softest steel, called No. 2 in the tables of experiments, had a tensile strength of only 30 tons per square inch, but the test plate made of it bore bending double without cracking, showing a great degree of toughness; while the most highly carbonised quality, No. 20, had the greatest tensile strength, amounting to 69 tons per square inch, but was so brittle that it snapped asunder without bending more than about 45° out of the straight line, as shown by the specimen exhibited. For the experiments on axles, in order to obtain the most correct results from wrought iron axles for comparison with those of steel, he got the best wrought iron axle he could of the regular faggotted make from a railway company, and also two scrap axles from makers who knew they were going to be tested; but the last two turned out worse than had been expected, and much inferior to the first, as seen from the table of experiments.

One circumstance to be noticed respecting the mode of testing the tensile strength of bars was that the results obtained with long test bars were different from those given by short ones. In a number of experiments upon this point he had found it to be regularly the case that if the test bar were turned down to the required diameter at one point only of its length it would stand one third more strain than if turned down to the same diameter throughout a length of 14 inches. This was a fact of much importance, as affecting the value of many experiments.

Mr. H. MAUDSLAY observed that in turning down a long length of the test bar each part of that length was subjected to the strain, and therefore the test was exposed to all the chances of weak places occurring from irregularity in make of the bar at any point of its length; but when the bar was turned down at one part only, the chance of breaking at a weak place was confined to that small length only.

Mr. VICKERS thought the result could not be merely an average of chances, for he had noticed that the bar was always stronger when turned down at one point only, in the manner described. He thought it might arise from the strain producing a greater effect in stretching the bar and reducing its diameter when turned down of uniform diameter for a long length, since steel always stretched considerably before breaking. The breakage occurred however at various points in the length turned down, not at the centre only.

The CHAIRMAN enquired whether the steel axles were in use on any railways.

Mr. VICKERS replied that steel axles were used almost universally on the German railways, and also steel tyres and wheels. A number of the steel axles of the make now shown were in use there, and some of the cast steel wheels. Very few steel axles had yet been tried in England, but many steel tyres were now used.

Mr. R. WILLIAMS observed that the number of blows sustained by the axles from the maximum height in the experiments represented only a small portion of their strength, since the axle was rendered much weaker by being reversed between each blow.

Mr. B. FOTHERGILL asked what amount of heating took place in the axle during testing, and whether any means were taken to cool it between the blows. In some experiments upon the fracture of axles he had found the heating considerable, and thought it was not a fair test to continue the blows when the axle had got hot, since its strength would then be affected.

Mr. VICKERS did not think the heat in these experiments had been of any importance, as the testing of each axle occupied 2 or 3 hours, on account of the time taken up in raising the weight between each blow; and the axle lost its heat so rapidly during the interval as never to require cooling.

Col. KENNEDY enquired what was the elastic strength of the different qualities of steel, or the limit to which they could be stretched without taking a permanent set. He thought it was of more importance to know this than the ultimate breaking strength.

Mr. VICKERS said he had not ascertained the elastic limit of the steel in the experiments.

Mr. E. Riley asked what iron the steel was made from, and how far it was free from carbon in its original state previous to being converted into steel.

Mr. Vickers said the iron used was Swedish iron, which he had tested previously and believed to be as free from carbon as possible.

Mr. E. Riley doubted the freedom of the iron from carbon, and believed a small quantity of carbon was essential in wrought iron, without which it was useless. From experiments he had made he had found that the best wrought iron after being melted was always red-short and would not work at all, but was useless as wrought iron; and considered this was due to its being deprived of the small percentage of carbon it contained by the scale on its surface and the air in the melting pot. He had also found experimentally that fused wrought iron from the best ores was red-short and useless when made by reducing them with too small an amount of carbon, so as to leave oxide of iron in the cinder, which prevented any carbon from combining with the iron. This defect however was easily remedied by adding carburet of manganese, which supplied the requisite amount of carbon; and moreover the oxide of manganese produced acted also as a useful flux in separating some of the impurities contained in the iron: the addition of 1 per cent. of carburet of manganese to fused wrought iron made the iron work well, and prevented its being red-short.

The Chairman knew no question of so much importance to engineers as the effect of carbon on iron and steel, since the various qualities of both depended mainly on the proportion of carbon combined with them. A haze of doubt still hung over the subject, and called for further investigations to clear it away; but the period was now dawning when iron could be used in the form of mild cast steel, and an age of steel appeared likely to supersede that of iron. Tabulated experiments giving definite results, such as those in the paper, were the most efficient means of solving the question; and such information placed in the hands of engineers was of special value in enabling them to draw their own conclusions from the results obtained.

He moved a vote of thanks to Mr. Vickers for his paper, which was passed.

The Meeting was then adjourned to the next day.

In the afternoon the Members visited the works of Messrs. Naylor Vickers and Co., where the process of casting a large steel crank axle was shown, the steel for which was melted in 70 pots and poured into a casting ladle fixed above the mould, whence it was run into the mould by lifting a plug in the bottom of the ladle. One of the solid cast steel disc wheels which had previously been tested as described at the meeting was broken to show the soundness and quality of the steel; and a number of the cast steel bells were also exhibited and rung.

The Members then visited the works of Messrs. John Brown and Co., to see the rolling of the armour plates; and the plates that had been fractured in the experiments described at the meeting were shown. At these works also, and at those of Messrs. Bessemer and Co., the Bessemer process of manufacturing cast steel by direct conversion from crude pig iron was seen in operation; and a number of specimens were shown of the rails and boiler plates &c. made from the steel.

A number of the principal manufacturing establishments in the town and neighbourhood were also opened to the inspection of the Members.

The Adjourned Meeting of the Members was held in the Music Hall, Surrey Street, Sheffield, on Thursday, 1st August, 1861; Sir William G. Armstrong, President, in the Chair.

The following paper was read:—

ON THE CONSTRUCTION AND ERECTION OF IRON PIERS AND SUPERSTRUCTURES FOR RAILWAY BRIDGES IN ALLUVIAL DISTRICTS.

BY LT.-COLONEL J. P. KENNEDY, OF LONDON.

The object of the present paper is to consider the most eligible construction for the Piers and Superstructures of Railway Bridges in alluvial districts, as regards economy in first cost, and facility and economy of erection in the colonies, in situations where the supply of skilled labour and mechanical appliances are very limited: and more especially in reference to the extension of railways as a means of facilitating the industrial development of the British colonies.

The mutual dependence of the several portions of the British empire renders it a matter of great importance to all branches of trade and manufactures that the greatest possible facilities should be furnished for transport and intercourse in the colonies; and that communications should be opened in the most rapid and economical manner, for enabling colonial produce to reach the seats of manufacture. The importance of this is especially seen when it is considered what a great and rapidly increasing portion of the total exported manufactures of this country finds its market in the colonies and particularly in India, and how rapidly this increase has progressed since improved means of communication have been adopted for conveying the manufactures into the interior of the country, and giving an outlet for the native produce and raw materials. Some remarkable facts are shown by a comparison of the consumption of British manufactures by the colonies and by the rest of the world; the total population of the British empire being now more than 206 millions, or as much as 1-5th of the whole population of the globe, of whom 6-7ths are colonists. The consumption of British exports by the colonies is more than half as much as that by all other countries, and even in the present deficiency of the required facilities of communication, their consumption has trebled in the last twelve years, while that of the

other countries has only doubled in the same time: although in India, from the great deficiency in means of communication, the average annual consumption by the whole population was only 1*s*. 2*d*. per head in 1855, increasing to 2*s*. 3*d*. per head or nearly double in 1859; whilst in Australia it amounted to more than £8 per head, and to between £1 and £4 per head in the other British colonies. The great step in improving the means of internal communication has been the introduction of railways, which have commenced an entirely new era in the development of the resources of these countries; and since the first starting of railways in India in 1849 a remarkable advance has taken place. The annual consumption of British produce has increased from 4½ millions sterling in the previous year to 10 millions in 1855, and to 19¾ millions in 1859; the value to this country having thus been quadrupled within eleven years, and even doubled within the four years ending in 1859, including the period of the mutiny with all its deranging effects on commerce.

In the employment of railways for this object a consideration of great moment is the mode of construction of the piers and superstructures of the bridges, which form so large a portion of the works of a railway in many parts of India and other colonies; the construction of the piers especially having a particular bearing in alluvial districts upon the practicability and cost and the consequent success of the line. A good illustration of this important subject is afforded by the works completed and in progress in the construction of the Bombay and Baroda Railway in India, with which the writer is connected; where a special construction has been adopted for the bridge piers and superstructures, in order to meet the difficulties of the alluvial district through which the railway passes, and attain facility and rapidity of erection combined with economy in total cost.

Most of the Indian railways take their course through rich alluvial plains and valleys where there is only one important natural impediment to their construction, consisting in the bridging of the rivers, many of which must be crossed within tidal influence; and all of them are swept by fierce monsoon currents, while their beds in general offer the worst class of foundations for the construction of masonry piers. They

thus combine the greatest impediments to the erection of the usual description of masonry bridges. The great cost of erecting a bridge across the Thames at London is generally known; and yet in that case there are the best engineering talent and the greatest mechanical aid immediately within reach; and although the natural impediments are of the same class, they are far inferior in degree to those met with in Indian rivers.

The line of country traversed by the Baroda Railway in its level course of 310 miles from Bombay to Ahmedabad is more intersected by rivers of the above character than any other railway in India. So vast did the difficulties appear that the very practicability of constructing the line was seriously disputed; and not without reason, if it were assumed that the bridge piers must be executed upon the old stereotyped masonry plan, and that the engineer would not adopt those modern and well tested improvements that were applicable to the case. To those however who knew the precise nature of the local difficulties as well as the modern engineering improvements by which they could be surmounted, it was clear that this line could be effectually and economically executed, provided such modern improvements were applied: but by no other means could a maximum financial return for the outlay, which ought to be the first principle in engineering, be secured. The object was therefore to show that it was practicable to overcome with rapidity and economy the great characteristic difficulty opposing the construction of Indian railways, even where most prominently encountered. The writer accordingly proceeded to ascertain first all the engineering and financial requirements, and to investigate the comparative merits of all well tested improvements calculated to meet them; whence it was ultimately concluded that to bridge Indian rivers in alluvial districts on the old principle of masonry or brickwork would be both tedious and ruinous to the undertaking; but that the most difficult rivers so situated may be economically bridged by adopting wrought or cast iron for the piers, and wrought iron in the superstructures. The writer finally arrived at one pattern of bridge, admitting of extension or contraction to meet all the variations of circumstances that occur in such cases, as to height or length of bridge and depth and nature of foundations.

The several applications of the plan to the different situations that are met with are shown in Plates 36 to 39. Fig. 1, Plate 36, is a general elevation, and Fig. 2 a transverse section, of the Taptee bridge, 1891 feet long, spanning a rapid tidal river; and Fig. 3 gives the section of the bed of the river with the variations in depth enlarged eight times, showing the applicability of the same construction of piers throughout the entire length of the bridge.

Fig. 4, Plate 37, shows the construction of piers adopted in strong tidal rivers, such as the Taptee and Nerbudda rivers, where the depth of floods reaches from 40 to 60 feet with a velocity of 6 to 10 miles per hour, and the force of the current acting alternately in opposite directions on the piers requires the addition of oblique piles to act as struts on both sides of the piers. The piers are composed of hollow cylindrical cast iron piles, of 1 inch thickness of metal and 2 feet 6 inches outside diameter, cast in 9 feet lengths weighing about 1¾ tons each, as shown enlarged in Figs. 11 to 14, Plate 40; these are of two principal patterns, for the portions of the piles above and below the ground. Those above the ground, Figs. 13 and 14, have flanges outside for bolting them together by twelve 1 inch bolts; while those underground, Figs. 11 and 12, have the flanges inside, bolted together by ten 1 inch bolts, and are flush on the outside so as to offer no resistance in penetrating the ground; they are large enough inside to leave room for a man getting in to bolt the several lengths together properly in the process of erecting. The foundation is obtained by one of Mitchell's screws at the bottom of each pile, of 4 feet 6 inches diameter, which finds its own foundation without the expense of cofferdams or any other artificial preparation of the ground. The upright piles are placed 14 feet apart centre to centre, and are sunk to a depth of about 20 feet in the ground; but where the ground is softer than usual they are carried down deeper, as shown by the dotted lines in Fig. 4, to obtain the requisite strength of foundation. The greatest length of pile used has been 45 feet below the ground and 72 feet above. The oblique piles forming the struts are inclined at an angle of about 30° to the upright piles; they are precisely the same in construction as the upright piles, and are joined to the latter at about the ordinary flood level by a cap cast at the proper

angle, which clips the body of the upright pile. The piles are all connected together above ground by horizontal and diagonal wrought iron bracing, attached to lugs cast on the piles by a pin at one end and a gib and cotter at the other, as shown in Figs. 13 and 14, Plate 40; Figs. 15 to 18 show sections of the horizontal T iron bracings A, and the diagonal angle iron bracings B. The several parts of the bracing act alternately as struts and ties according to the direction of the current, and in consequence of this alternate strain an accurate fit of the bracing is required; to ensure this the joints at one end of each are therefore left to be done in India from measurement on the site, this being the only forging required in India. The outside piles are faced with a double row of timber as a fender to protect them against shocks from anything floating in the water and brought down by the current. The weight of a single complete pier of five piles for two lines of rails, 63 feet high from the foundations, is 75½ tons, and the cost £624 delivered in London.

Fig. 5, Plate 37, is a side elevation of one of the spans of the bridge, shown to a larger scale in Fig. 19, Plate 41, showing the construction of the superstructure, which is that known as Warren's triangular system. Fig. 20 is a plan of one roadway, and Figs. 21 and 22, Plate 42, are an enlarged elevation of the double standard carrying the ends of the girders, and a side elevation of the girder and standard. Figs. 23 to 29, Plate 43, are sections of the bars composing the girders. This form of girder, when manufactured and accurately fitted in England, requires the smallest amount of skilled labour for its erection abroad on reaching its destination; only a few pins and bolts have to be put in for completing the girders, and the skilled labour required for rivetting box girders or lattice girders is avoided. As it is considered that uniformity of parts, as far as practicable, is of as great importance in bridge work as in other mechanical structures, a uniform span of 60 feet is adopted for all the iron bridges on the line, this being considered the most economical in reference to the general heights of the piers. One end of each girder is fixed on the pier, while the other end is left free to move and carried on a pair of small rollers C, Fig. 22, to allow of expansion and contraction. The weight of the entire 60 feet superstructure for

a single line of rails is 24 tons, being 8 cwts. per foot run; and the cost at the present rate of iron is about £400.

Fig. 7, Plate 38, shows the construction of piers adopted for inland rivers with deep water, say 20 to 50 feet deep, but not tidal, where the current is always in one direction only, as shown by the arrow. Here the oblique piles acting as struts are required only on the lower side of the bridge, and the timber fenders only on the upper side. Fig. 8, Plate 39, shows the piers for inland rivers with shallow water of not more than 20 feet depth, where the oblique piles can be dispensed with altogether. Where there is a rock foundation, the screws are omitted, and the piles are simply let into the rock about 2 feet and filled round with cement, as shown in Fig. 9, Plate 39, allowing of great rapidity of erection in this case. The position of the roadway may be either between the main girders, or upon the top of them, as shown in Fig. 10, Plate 39. The upper position is preferable for the roadway, because it combines the effect of both the main girders in resisting forces that tend to produce buckling of the compression beams. The upper or lower position of the roadway however is decided by the amount of headway under the bridge, or the clearance between the bridge superstructure and the highest known flood level of the river, which should not be less than 5 feet. In every case the power of the compression beams to resist buckling is made ample, and a horizontal diagonal bracing of T iron is provided between the cross girders carrying the roadway, as shown in the plan, Fig. 20, Plate 41, continued from pier to pier; and where the roadway is on the top of the main girders, oblique stays are added, as shown in Fig. 10, Plate 39, to secure the requisite stability and freedom from vibration in the roadway and girders.

A valuable proof of the strength of the piers erected in the manner above described, as shown in the drawings, was afforded by the exposure of the Nerbudda viaduct on the Baroda line to the monsoon of 1860 whilst still in an incomplete state, the works having been suddenly stopped by the cholera breaking out among the men. There were at the time only two piles erected at the last pier which reached into the middle of the stream, without any oblique piles to serve as struts in

supporting it, as shown in Fig. 6, Plate 37; but the pier resisted the deepest and fiercest current of the river without sustaining any injury. At this bridge greater rapidity in screwing down the pier piles was latterly attained by applying animal power direct at the extremities of 40 feet levers made fast to the piles, without the intervention of crab winches or other multiplying wheels. Four of these levers, with 8 bullocks yoked to each, were applied to screw every pile. This plan would be applicable to all pier sites not permanently covered with water. Where any considerable depth of water exists, the practice hitherto has been to erect a temporary staging or platform upon timber piles, from which the permanent iron piles are screwed down by a lever and capstan worked by crab winches: but probably a more economical mode would be to use a floating stage carried upon well anchored pontoons. The principal element of strength in these bridge piers is the firm and accurate fixing of the horizontal and diagonal bracings between the piles from the bed of the river upwards. This and other necessary operations in deep water are effected by submarine fitters furnished with Heinke's diving helmets and dresses, which are indispensable in such cases.

Previous to adopting the Warren system for the bridge superstructures, as shown in Figs. 19 and 20, Plate 41, the writer tested a girder of this construction of 60 feet span to the breaking point; and finding the results generally satisfactory, strengthened the parts very considerably in the subsequent designs, rejecting all cast iron, and increasing the quantity of wrought iron beyond previous practice. An additional strength was thereby obtained which has already proved of great service, having enabled the Wiswamuntra bridge to resist successfully the shock to which it was exposed by an accident arising from a malicious plot for destroying a special train on the 17th January 1861; the train was thrown off the line by a rail placed across in front of the abutment, and broke some of the cross girders supporting the rails; but it was brought to a stand without material damage to the main girders and without serious injury to any one in the train. The regular test to which the superstructures have been submitted in England was 2 tons per foot run, or about double the maximum load that can be placed upon them in practice. This

test load was rolled on in trucks from a siding: it caused a deflection of only $\frac{5}{8}$ inch in the centre of each 60 feet span, and upon removing the load the girders recovered their original camber without taking any permanent set. The greatest strain to which any portion of the girders is subjected under the heaviest practical load is $3\frac{3}{4}$ tons per square inch of section.

The piers and superstructures for 95 bridges on this plan of construction have now been sent to India, comprising 477 spans, and making about 6 miles of viaducts upon the Baroda Railway; and the trains on the 132 miles opened within the last year pass over 33 bridges comprising 215 spans of 60 feet each. There has not been a single failure in the foundations with the iron pile piers, though nearly all the foundations were bad; whilst the attempt to erect masonry abutments even for 10 and 20 feet spans has failed in several instances in similar localities.

The rapidity of erection afforded by this mode of construction is well illustrated by the progress made on the second or central division of the Baroda Railway, extending over a length of 80 miles and including the most difficult part of the entire line. Possession of the land for this portion of the line was obtained in October 1858. The average amount of iron bridge viaduct on the northern half of this division, including the Taptee viaduct, was twice the average of the whole: about 40 miles in this locality, or 1-8th of the entire line, included one quarter of the total amount of bridge work. The Taptee bridge, 1891 feet long, spanning a tidal river and erected on an alluvial bed, shown in the diagram, Fig. 1, Plate 36, was opened for the passage of trains in November 1860, within one year from the sinking of the first pile: this great work ranks second in point of difficulty on the entire line. These 40 miles of railway just completed occupied about $2\frac{1}{2}$ years in construction, including 18 iron bridges making up more than a mile and a half of viaduct, which were erected in only 15 months, a remarkable achievement in railway operations. These works being the first of the description executed upon a large scale, the writer was not able to meet with engineers experienced in their erection. Only one of the engineers on the line had previously erected a Warren girder, and only one

had previously sunk a screw pile. None of the others had erected either piers or superstructures of this class; yet in this their first effort in the erection of railway bridges upon iron screw piles their success was as above stated; and with their increased experience they can now erect as many piers at a time as it might be found advisable to carry on simultaneously, each being completed in a fortnight; and they could cover the piers with their superstructures at the rate of one span in every two days. This rate of erection was nearly attained in practice in the construction of the division of the line above referred to.

An important essential to economy and rapidity of construction is to provide beforehand a large proportion of the permanent way and bridge materials, and to have both of them in readiness at the proper commencing point of the line before the earthworks are undertaken. This precaution would add to the economy of the results by enabling the materials to be carried forwards to their intended sites along the railway itself as soon as the rails were laid on formation level; and would admit of rapid ballasting as soon as the earthworks had received their first rains or monsoon seasoning. It would besides have a beneficial effect in consolidating the banks by the transit of heavy loads prior to the ballasting and before opening the line for traffic. In order to secure the greatest regularity in the supply of the materials in India, all the portions of each pier and each span of superstructure should be shipped together in the same vessel.

The system of construction now described aims at maintaining the greatest practicable uniformity of parts and the smallest variety, with the greatest durability of pattern throughout all branches of the railway works. This can only be secured by well considered designs based upon strict tests. The first templates should be the best fitted to their object of any at the time in existence, and should be preserved until some indisputable improvement required a change. The greatest judicious uniformity of parts and designs is essential to the greatest attainable economy, rapidity, and certainty, both in construction and in after working. On this railway precise uniformity has been established between the corresponding parts of every pier and of every girder in its 95 iron bridges. Without such uniformity it would have

been impossible to secure either the greatest precision of manufacture at home, the greatest rapidity of erection abroad, or freedom from the cost, inconvenience, and delay which must attend losses at sea, when each work is upon a special and separate design. In erecting the work each engineer, artificer, and labourer becomes rapidly accustomed to his particular duty and acquires increased expertness in its performance. The work at one point being completed, the men are moved to similar operations elsewhere with similar materials. The object has been to apply to the construction of great public works the principle of manufacturing success, namely repetition of the same operations by the same men throughout.

From the present state of iron structures of this class that have been standing for many years and have been well taken care of, their probable duration for 100 years may be inferred. This would bring them to between the ages of the old Westminster and Blackfriars masonry bridges: the former of these has for the last six years been in process of rebuilding, and the latter is awaiting a similar renovation. A comparison of the rate of cost of the Baroda Railway iron bridges with that of the old Westminster masonry bridge shows that the interest upon the capital saved by adopting the former would in about three years amount to their entire cost, even in the absence of effectual precautions against oxidation. There is however no desideratum in practical engineering of greater importance than the discovery of such a protection against oxidation as shall materially extend the durability of iron structures.

The cost of the entire construction of the Baroda line may amount to about £11,000 per mile; but had the ordinary method of constructing the bridges been adopted, even if at all practicable, the cost must have reached from £16,000 to £18,000 per mile.

In connexion with the railways now in progress in India as main trunks, and considering that the country is at present absolutely without secondary roads converging to them, it becomes important to settle what is the most profitable description of secondary roads to adopt. That plan will be best which shall enable goods to be conveyed most cheaply, taking into account first cost, maintenance, and working

expenses. Comparing an ordinary metalled road with a light tramway capable of being worked either by animal power or by a small locomotive engine, the cost of construction and the maintenance of the tramway may be assumed at double the amount per mile of the ordinary road; but the tractive effect of the same power on the tramway would be eight times that on the road, the effect of gradients being the same on each. Comparing steam with animal power for cost of traction, the former may be taken at half the cost of the latter with four times the speed. It may therefore be considered that the total cost of haulage by steam power on a tramway is one half that of animal power on a tramway, or one sixteenth that of animal power on ordinary roads, the speed being four times as great in both cases.

It is satisfactory that one native Indian prince, the Guicowar of Baroda, has set the example of constructing from state funds a tramroad converging to a trunk railway, having commenced a line of 20 miles length through a rich district from Dubboee to the Meagaum Station on the Baroda line. This is to be opened as a horse tramroad before the next cotton season. Mr. Forde, the late chief engineer of the Baroda line, has undertaken the construction of this tramroad at a cost of £1300 per mile, using rails 12 lbs. per yard and a 2 feet 6 inches gauge. In the writer's opinion both the gauge of a tramroad and the weight of rail ought to be considerably increased beyond those dimensions; the gauge to be say 3 feet 6 inches, and the rail 28 lbs. per yard at least. The introduction of a minor class of railway or tramroad is a question of much importance, requiring the forethought and distinct arrangement of the government. It is quite as essential that a uniform gauge of road, height and gauge of buffers, and clearance gauge, &c., should be established for such minor roads as for the main trunk lines; otherwise there must be endless and costly unloading and reloading as the system becomes developed.

In conclusion it may be observed, with reference to the extension of railway communication in India more especially, that, with due facilities from the government in the construction and working arrangements, the railway companies will find themselves in a most favourable position to carry out their task, with every element that can secure the most satisfactory results. Taking the Baroda line as a

sample, it traverses a vast populous and most productive district; its ruling gradient is 1 in 500; the cost of construction is expected to average about £11,000 per mile, or one fifth of the rate of much easier lines executed in England; and it is protected by the establishment of a moderate rate of train speed. Such conditions must ensure safe travelling at low fares for the public, together with a liberal remuneration to the shareholders, and thus tend to restore the confidence of capitalists in similar beneficial operations, so essential to the progress both of England and the colonies.

Col. Kennedy observed that the extent of country to be supplied by railways in India was very great, averaging 1000 miles across from west to east and considerably more from north to south. It was intersected by two principal ranges of mountains, the Vindea central range running from west to east, and the Syhadree range 2000 feet high running from the centre of India southwards along the west coast, with a steep declivity towards the sea on the western side but a gradual fall inland on the eastern. In the case of the Bombay and Baroda line great care had been necessary in surveying the country beforehand, to make sure that all branch lines intended to be constructed afterwards would be practicable, and 4000 miles of ground were examined before any steps were taken in commencing the works: this was the more important in so mountainous a country, in order to get the best possible levels along the entire course of the line, and the result was a ruling gradient of 1 in 500. The population of the country and its capabilities of supplying produce were so great as to ensure an enormous traffic for all the railways, and financial difficulties alone kept things back at present; but he was convinced a dividend might be relied upon fully sufficient to secure the requisite capital being raised without the necessity for a government guarantee, which formed as yet the principal obstacle. The vast importance of ready communication through India might be judged of

from the fact that India already consumed a larger amount of British produce than any other country; hence it was that, while her colonies were the main support of the industrial classes at home, England must look to her colonies and to India especially for the maintenance and advancement of that industry; and facility of road traffic was therefore essential for increasing the demand for home productions and for returning larger supplies of raw material.

From the nature of the country it frequently occurred in India that the practicability of building a bridge in a particular locality was the consideration which determined whether there should be a road or not; and the same condition decided the question also as to a railway. The large majority of the lines had to follow the valleys and to cross the rivers frequently, requiring a special construction of bridge piers for the alluvial soil where solid masonry piers were most costly if not impracticable. The piers were thus of vital importance: many kinds of superstructure might be adopted, but on the piers depended the practicability of making the railway. Of the Thames bridges some cost half a million or more, although they were only about 900 feet long; but on the Indian lines miles of bridges had to be dealt with, which must be strong enough to withstand the fierce monsoon floods running at 6 to 10 miles per hour. Hence great strength and durability were necessary in the bridge piers, combined with cheapness of construction; otherwise a railway could not be attempted with any prospect of a successful issue.

Mr. C. Markham asked how the mode of screwing in the piles by animal power was carried out with the piles in the centre of the river.

Col. Kennedy replied that the use of animal power had only latterly been adopted at the great Nerbudda bridge, where a large part of the river bed was uncovered at low water, and it was only in such situations that animal power had been made available direct by means of a long lever. The general practice had been, where the foundations were not always under water, to hoist the piles into the proper position by shear legs and hold them in this position by guides whilst they were screwed into the ground by a crab winch acting on the end of a lever; but where the ground was always covered with water, a staging was erected on timber piles surrounding the site of the pier.

Mr. C. MARKHAM observed that in the construction of pier now shown the centre pile would have to carry double the weight on the outside piles whenever two trains passed each other on the bridge, but as the centre and outside piles were of the same size, the pressure on the foundations was unequally distributed; and he enquired why a double pile had not been used in the centre, or a single pile of larger size, since the pressure of the load was entirely vertical, and he did not think the bracing adopted would distribute it sufficiently to render the strain equal on all the piles. There had recently been an instance in America of a timber railway bridge constructed of three girders of equal strength breaking down under the passage of two trains, in consequence of the middle girder having to carry half of the entire load.

Col. KENNEDY replied that the strong diagonal bracing of wrought iron shown in the drawings, when accurately fitted, carried the load effectually on to the side piles; so that wherever the weight might be, it was equally distributed over the entire foundation. The centre piles had been proved to have ample strength for the strains to be resisted; for in erecting the Nerbudda bridge the monsoon floods occurred at a time when the piers had advanced into the middle of the river, and only two piles had then been erected in the last pier, without being thoroughly braced; yet the pier withstood the whole force of the current, though it could have had only a small portion of the strength possessed when completed. In the American bridge referred to, the centre girder when bearing the double load of two trains passing at the same time would receive no support from any adjacent parts of the structure: but the piles of the Baroda bridge piers were mutually supported by the copious and accurately fitted bracing, which necessarily distributed the load equally over the pile foundations.

The CHAIRMAN thought the diagonal bracing shown in the drawings would certainly distribute the weight equally on all the piles, when properly constructed; and it was therefore of great importance that the fitting should be accurately done in erecting the piers.

Mr. C. MARKHAM asked whether there had been any difficulty in fitting together the several lengths of the piles securely, in consequence of the joints of the castings not being faced up.

Col. KENNEDY replied there was no difficulty in making a secure joint; the joints of the castings though not planed were chipped to a level face, and bolted together with ten 1 inch bolts for inside flanges and twelve 1 inch bolts for outside flanges; and the joints were found quite satisfactory, whilst the expense of planing them was saved.

Mr. H. BESSEMER thought the construction of the pier now described was a valuable application of tubular piles where brick foundations were impossible on account of the nature of the ground. The use of screw piles throughout the structure entailed an amount of labour in screwing them down which might perhaps be avoided in some instances by the plan that he had seen adopted in the pier lately constructed at Southport, where there was difficulty in getting a foundation and cofferdams would have been very expensive, the ground being nothing but sand to a great depth, covered with water at each high tide. The plan adopted was a very simple system, applicable generally for foundations in sand, and consisted in employing tubular piles built up of a number of lengths, having a broad flat disc at the bottom, 4 feet diameter, with a small hole in the centre, through which a stream of water was allowed to flow from a pipe supplied by the water main of the town: the water displaced the sand from under the disc, and in 30 or 40 minutes the pile was sunk 10 or 12 feet deep in this manner; the water was then shut off and left the pile resting on a broad level surface, which afforded resistance enough to prevent the pile sinking further under a heavy load. The only labour required would be for pumping the water, where there was not a supply at hand.

Col. KENNEDY said that was Mr. Brunlees' plan, and it had been very successfully applied for the railway viaduct across the sands of Morecambe Bay. It was an excellent mode of sinking piles in sand and no doubt quicker and easier than by screwing them down; but was applicable only where the foundation consisted of sand alone. In the Indian rivers however the soil was alluvial, containing boulders intermixed with it, which could not be washed away by a stream of water, and the piles had therefore to be screwed in. In one place at the Nerbudda bridge a quicksand obliged the piles to be carried to a

depth of 45 feet; but as they passed through other soil also, screw piles were necessary even in this instance.

Mr. E. T. Bellhouse enquired who were the makers of the ironwork for the bridges; he thought a great deal of the success of such works depended on the manner in which they were executed in England previous to erection abroad, and a work of such magnitude as the bridges now described reflected great credit on the makers. He asked also whether the erection in India was superintended by English engineers, and whether it was performed by native labourers or workmen sent out from England.

With regard to the centre pile in each pier he thought it was quite right in this case to make it the same size as the others, and the diagonal bracing was quite sufficient to ensure every single pile receiving an equal share of the weight. It would be very inconvenient to have another pattern of pile, and in that class of work for foreign countries it was highly important to secure simplicity and uniformity of construction, to save cost and trouble in erection.

A serious question in reference to all iron structures, particularly those of wrought iron, was the means of preserving them from oxidation; and he was not satisfied that the right mode of employing wrought iron in bridges and roofs had yet been arrived at, for giving it the greatest protection from rusting. He had had to make several iron structures of similar character, and thought there was too strong a tendency generally to aim at cheapness in first cost, by running the work too fine in size and weight of the parts; and a warning was needed he thought to recall the consideration of durability as of equal importance with that of first cost. Already many proofs had been received of the danger of carrying lightness of construction to an extreme: some fine iron roofs that had been erected within the last twenty years had come down suddenly. He had seen few iron roofs that were properly painted to keep them from rusting; and unless this were frequently done, an accident might occur any day from the metal having become gradually corroded at some unseen part. Corrugated iron also, whether galvanised or not, soon began to break into holes unless frequently cleaned and painted. This was even a more important consideration in the large wrought iron bridges, of which so

many had lately been put up, and he feared some of them would show signs of serious decay before many more years had passed. It was therefore desirable to lay great stress on the necessity of efficiently painting all iron structures, for keeping them in thorough repair and enabling them to last for many years.

Col. KENNEDY said that the whole of the ironwork for the bridges had been done by four makers, two of whom supplied the piers and two the superstructure, and the whole of the work had proved thoroughly satisfactory. Of the piers nearly half were supplied by the Horseley Iron Co., Tipton, and the rest by the Victoria Iron Co., Derby. There was always a difficulty in carrying cast iron safely across the sea, from the great risk of breakage in shipment and in conveyance by land as well as the chance of disasters at sea; but they had had altogether only about 5 per cent. of loss from all causes in the cast iron work, which was a smaller proportion than he had ever heard of before in similar cases. The first part of the superstructure was made by Messrs. Kennard at Crumlin; but the greater portion by Messrs. Westwood Bailey and Campbell, London Yard, Isle of Dogs. Every wrought iron girder must have some deflection under a load, but the proof of accuracy of workmanship and correct fitting of all the parts was that it should come back to its original position when the load was taken off without any permanent set. For the erection of the work in India the engineers and foremen alone were sent out from England, and all the other workmen employed were natives: the natives made good workmen in a very short time and then got on rapidly with the work. As a consequence of the additional employment, the price of labour had now been doubled by the railway works throughout the district traversed by the line.

He fully concurred in condemning the practice of cutting down the dimensions too fine in such structures, and considered a liberal margin ought to be left beyond the calculated strength, to allow for strains which could not be taken account of with the same accuracy as simple transverse and longitudinal strains. Buckling was a frequent source of extra strain, particularly where there was any considerable depth of girder, and therefore required to be carefully provided against by increasing the size of the sections and arranging the iron in such a

form as would enable it best to resist buckling under compression. In the girders now described all the bars subject to compression were made of a cross shape in section, as shown by the drawings, (Plate 43); and the greatest strain either of tension or compression on any part of the girders amounted to only $3\frac{3}{4}$ tons per square inch under the heaviest practical load.

The Chairman enquired whether the girders were joined up into one continuous length so as to increase their strength, or whether each span had separate bearings at the ends.

Col. Kennedy replied that each span had separate bearings, in order to allow perfect freedom for expansion and contraction. Each girder was supported by the top or compression beam, which was fixed to the pier at one end, the other end being left free to move on rollers. The greatest longitudinal motion at present observed in 24 hours amounted to $\frac{3}{16}$ inch in one span of 60 feet. In the dimensions of the girders great allowance had been made to provide against buckling and the strains produced by concussions, and there were only a very few places where the strain ever came up to the maximum of $3\frac{3}{4}$ tons per square inch, while everywhere else it was much below that amount, so that the strains never approached the elastic limit of the iron. The accident to the Wiswamuntra bridge mentioned in the paper was a sufficient evidence of the large margin of strength that existed; for though the beams were bulged out and otherwise damaged in that case by the train running against them when it was thrown off the rails, they still held up the load, and the bridge was not broken down although only a single line of rails had been constructed.

Mr. A. B. Cochrane asked whether the several lengths of the piles were cast vertically, in order to ensure the same thickness of metal all round, and whether the joints required any fitting to go together properly.

Col. Kennedy said the pile lengths were cast vertically, and the joints were generally cast with sufficient accuracy to go together without any fitting; but where necessary they were chipped to a level face, and care was taken to ensure a uniform thickness of metal throughout the flanges.

The Chairman enquired what means had been adopted to protect the ironwork of the bridges from corrosion, and whether galvanising the iron had been tried. The great variety of situations in which iron structures were placed would of course cause the work to be differently affected in different cases.

Col. Kennedy replied that every piece of the ironwork was dipped when hot in a bath of linseed oil, and had afterwards two coats of good oil paint. After erection they relied upon frequent and thorough painting for keeping the iron from rusting. From an examination of several old iron structures he found that the cast iron generally stood well, but the wrought iron showed evidences of corrosion after it had been up about 20 years, and it could never be relied on unless frequently painted or otherwise protected. He had not tried galvanised iron, having seen several roofs constructed of it in which large holes had been made by corrosion.

The prevention of iron from rusting was a question of general importance, and he thought every encouragement should be given to investigation of the subject, with a view to obtaining some really permanent protection. It was quite clear that even with its present liability to oxidation iron made decidedly the cheapest structure for large bridges in general, particularly in alluvial districts: but its durability and renewal were dependent mainly on its thorough protection from oxidation. The object to be sought was not simply to secure the best protection out of a number of modes, of which all might be defective; but to arrive at an absolute means of preservation if that were possible.

Mr. J. F. Spencer observed that tar had proved a very effective material for preserving the bottoms of iron ships from rusting, and was applied also inside the vessels. On the Clyde large ships of 2000 or 3000 tons burden were protected inside with a coat of a varnish made from purified coal tar, which was found a very efficient protection. A clean surface of the iron for laying on the varnish was all that was required, and it had a fine polish; the coat lasted 7 or 8 years when protected by a lining of woodwork in front. The varnish could be laid on cold, and the smell was all gone in a few days; it cost only about 2*s*. per gallon, which was much cheaper than red paint. This

plan had also been applied to the inside of steam boilers, where the uptake from the furnace passed through the steam room of the boiler, and it entirely prevented oxidation and scaling of the iron from the action of the steam; he thought it likely therefore to be suitable for such structures as the bridges described in the paper.

Mr. H. W. Harman enquired what margin had been allowed in calculating the breaking strain of the girders.

Col. Kennedy considered it was of little importance to calculate the ultimate breaking strain, since that was never likely to be approached in practice; it was more important to keep in view the elastic limit of strength, which he thought might be calculated at about 11 or 12 tons per square inch for wrought iron. If the girders were overweighted a permanent set must be produced; but when the size of the ironwork was calculated so as to keep the maximum strain under one third of the elastic strength, as in the present instance, then no permanent set would occur, if the fittings were all accurately done.

Mr. H. W. Harman thought it was possible to have a certain amount of permanent set without at all detracting from the strength of the girder. As regarded the construction of bridge that had been described, it seemed well adapted for the particular circumstances that had to be met, being specially designed for the alluvial soil of India and for facility of transport from this country and of erection abroad: but he supposed it was not considered otherwise superior to those more generally adopted in England, where the circumstances were in so many respects different. He was not aware of any bridges of that construction which had been up for many years at present; and being engaged himself in extensive wrought iron girder works he thought the more solid any bridge work was made the better and more durable it would prove, and on that account preferred boiler plate girders wherever practicable instead of lattice girders. In the present instance he observed that many of the pins in the diagonal bracing of the piers were below water and had to be put in by divers; these could not be examined either then or afterwards, but the divers must be trusted to for putting them in securely, and if any of the pins were omitted the whole pier would be weakened, since the

weakest part limited the strength of the whole. He thought the paper afforded very valuable and interesting information in the experience of erecting that kind of bridge on so extended a scale.

Col. KENNEDY said that kind of construction for bridges was only of recent date, but he knew of some bridges of the class which had already been up 7 or 8 years. Some of the pins of the diagonal bracing must of course be put in under water: but the joints of the several lengths of the piles were bolted together above water before the piles were screwed down. The piles were filled with concrete, which made them solid inside, so that each pile stood on a solid foundation of 4½ feet diameter.

Mr. H. W. HARMAN asked whether there was not some difficulty in getting the piles screwed down into the ground true in level, from inequalities in the nature of the ground; and whether any of the piles had been broken in screwing down.

Col. KENNEDY replied that there was some difficulty in getting the piles correct in level, but it was managed by screwing them down a little further if necessary; and as there were four lugs at each end of the several lengths for attaching the diagonal bracing, the level could be adjusted to one quarter of a revolution of the screw. Where the piles stood on a rock foundation a piece of the required length was cut off the bottom of the lowest length, leaving the flange at top for bolting to the next length; or else the rock was cut away deeper to get the proper level. A few cases had occurred of a pile being broken in screwing down, and it was then very difficult to get the screw out again; this was one of the chief difficulties that had been met with in erecting the bridges. At the Nerbudda bridge the sudden abandonment of the work caused by an outbreak of cholera and followed by monsoon floods left some single piles unsupported, which were broken; and one or two of these could not be got out again, so that it became necessary to alter the spans in two cases, selecting fresh sites for the piers in order to get clear of the broken piles. Rapidity of fixing was of special importance in India, for on account of floods and storms the working year for such operations could be reckoned at only about 8 months; and the facility of erection with this construction of piers and superstructure was so great that by

beginning at both ends at the same time they could now bridge the broadest river in a single season.

The CHAIRMAN observed that there was one objection to the Warren girder in its depending upon each single part for its safety, for if one of the pins were to give way the whole girder would come down. That was not the case in rivetted work, where a single rivet might fail without affecting the strength of the girder.

Col. KENNEDY remarked that the parts on which the safety of the girder depended were simple in construction and not numerous, being merely the cylindrical turned pins fitting into the joint holes.

Mr. H. MAUDSLAY thought a great practical advantage had been gained in the construction of bridge now described by reducing that class of work to a regular system, with the least possible variety of parts and the greatest amount of repetition, which were most important objects to be aimed at in mechanical operations. One valuable result obtained was that the loss of any one piece of the work in erecting did not affect the completion of the whole, as all the parts were made to exactly the same patterns.

He thought they were much indebted to Col. Kennedy for his elaborate and careful paper containing so much valuable and practical information, and moved a vote of thanks to him, which was passed.

The following paper was then read :—

ON CAST IRON TUBBING USED IN SINKING SHAFTS.

By Mr. JOHN BROWN, of Barnsley.

The object of the present paper is to describe the mode now generally adopted in coal mining districts to stop back the feeders of water met with in sinking to the seams of coal, and thus obviate the necessity for pumping. Without giving an historical account of the various schemes that have from time to time been devised for this purpose, it may be mentioned that the first kinds of tubbing used were formed of timber, in the shape either of planks or of a series of solid kerbs, technically termed "cribs," which were wedged tight with wooden wedges. These modes of keeping back feeders of water have now been almost altogether superseded by the use of cast iron tubbing. The course pursued in fixing the tubbing varies to some extent in different districts, but not materially; and the following description of the method practised under the writer's superintendence at sinkings in the midland counties will give generally an accurate account of the whole.

The tubbing consists of plates of cast iron forming segments of the circumference of the shaft; these are built course upon course to the required height, upon a cast iron foundation called a "wedging crib," as shown in Plates 44 to 46. Fig. 1, Plate 44, is a vertical section of a shaft 10 feet in diameter, showing the bottom iron wedging crib A, with an oak one B below it, eight rings of tubbing CC, each 2 feet in height, and the top iron wedging crib D. Fig. 2, Plate 45, is a plan of the tubbing; and Fig. 3 is a plan of the iron wedging crib A. Fig. 4, Plate 46, is a back elevation of one of the tubbing plates, to a larger scale, showing the arrangement of the ribs by which it is strengthened; and Figs. 5 to 8 are horizontal and vertical sections of the plate. Fig. 9 is a section of the iron wedging crib.

In the case of sinking a shaft which it has been previously determined shall be tubbed, the best mode is to hang the lift of pumps either by means of pulley blocks, or what is better still by powerful screws of a sufficient length to permit an ordinary pump tree to be attached and lowered from time to time as the sinking progresses. Some plan of this kind is requisite, because the space which has to be tubbed must be kept quite clear from pumping stays, as it is necessary to have a free access to the sides of the shaft all round the pumps. After sinking below the feeder of water, the first sound stratum met with should be chosen as a foundation upon which to place the cast iron wedging crib A, Fig. 1, Plate 44, for supporting the tubbing; and to preserve this foundation unshaken and free from cracks it is necessary to avoid the use of gunpowder in sinking down the few yards further which are required to afford room for the workmen whilst wedging the crib, and also as a "sump" or well to keep the suction pipe of the pump covered with water and prevent its being continually "on blast."

A space being cut out all round the shaft, as shown at E, Fig. 1, Plate 44, and a perfectly horizontal bed prepared by dressing with a chisel, the iron wedging crib A is laid upon it; dry sheathing deals of about $\frac{3}{8}$ inch thickness and quite free from knots are placed between each segment of the crib, as shown in the plan, Fig. 3, Plate 45. The space F at the back of the crib is then filled up as closely as possible with blocks of dry deal to the height of the crib, the grain being placed vertically; and dry deal wedges, 8 to 9 inches long, $1\frac{1}{8}$ to 2 inches broad, and $\frac{1}{2}$ inch thick at the top, are then driven in until the spaces are closed. Chisels similar to a shipwright's caulking chisel, but with a projection on each side the head, are now driven downwards by heavy hammers, and then drawn out by a lever with a claw at one end which passes under the chisel head; a wedge is then inserted in the hole and driven down as low as possible. This process is continued until it is impossible to drive in another wedge. The true test of a crib being sufficiently wedged is to find that in no part of the deal blocks F can the iron chisel be driven in, whether placed parallel with or at right angles to the crib; when arrived at this stage, the chisel may be inserted as far as the extent of the tapered edge,

but upon attempting to drive it further down even with a heavy hammer, and with the full force of both hands holding it down from above, the chisel will fly up with considerable violence. To secure the wedging crib in a shaft 10 feet diameter in this manner will require 4 or 5 men for not less than 60 to 70 hours. The spaces between the ends of the segments of the crib must then be filled with wood wedges until no more can be inserted. Great care should be exercised to collect the small streams of water that are usually found running down the sides of a wet sinking shaft, and prevent them from falling upon the space at the back of the wedging crib, as it is indispensable that the whole of the wood blocks and wedges be kept dry.

If a good sound foundation be met with free from cracks and fissures, and the wedging crib be laid and maintained perfectly horizontal and of the proper diameter inside, and wedged to the extent above described, it may safely be concluded that the most important part of the work is accomplished: the insertion of the tubbing of course requires considerable care, but unless the crib be laid true and securely the work must necessarily be imperfect and to some extent unsound. In the case of a very long column of tubbing it is desirable to use two or three wedging cribs placed upon one another, each crib being wedged in the manner described: and frequently an oak crib 6 inches thick and 18 inches broad is placed upon the foundation after it has been dressed off, as shown at B in Fig. 1, upon which the iron crib is then laid and wedged as already described. This wooden crib is wedged, but not so tightly as the iron one; since it is found that excessive wedging will cause a wood crib to rise and become warped. The wooden crib underneath gives facilities for underpinning with masonry, or for joining up a lower series of tubbing plates, as the necessary depth in the wood can be readily cut away.

When the wedging crib is completed, deal sheathing ⅜ inch thick and 4½ inches broad, cut to the proper radius of the shaft, is placed upon the rebate G at the front of the crib, Fig. 9, Plate 46, and upon this is fixed the first ring of tubbing plates. Each ring of tubbing is so placed that the vertical joints between the segments are opposite

to the middle of the segments in the rings above and below, as shown in Fig. 1; and the lowest ring also breaks joint with the wedging crib. Deal sheathing of a similar kind is placed between the vertical and horizontal joints of each ring, as shown in Figs. 5 to 8, Plate 46, the end of the grain always being presented to the shaft. In the case of all the upper plates pieces of deal 2 feet long and cut in a wedge shape are inserted at the back between the tubbing and the rock, as shown at H in Figs. 1 and 2; one piece is placed with the thick end downwards, at the back of the centre and ends of the segments, and another wedge piece with the point downwards is then driven in so as to tighten the whole and prevent the segments being driven backwards during the process of wedging. But the space E at the back of the two lowest rings being greater than in the upper necessitates rather a different treatment; strong pieces of timber are driven in with one end against the rock and the other against the back of the tubbing. As each ring of tubbing is built up, the vertical joints are slightly wedged with deal wedges 4 inches long; but no wedging is done to the horizontal joints until all the tubbing is fixed. The space E at the back of the two lowest rings should be filled up with some material that the water will force down into the crevices and form a water-tight mixture: oakum, horse dung, riddled soil, &c., are very good for this purpose.

If the feeders of water be found near the surface, it may only be necessary to carry up the tubbing plates to a higher level than that to which the water will rise, and then securely and tightly pin them up to the crib and brickwork above. But where the water is met with at a considerable depth and would rise above the stratum which yields it, an iron wedging crib D, Fig. 1, Plate 44, must be put in at the first sound place above, and fixed in the same manner as the bottom crib A; the tubbing is then built up ring by ring, and joined up to this top crib, which has a rebate upon the underside to receive the deal sheathing. A single row of wedges must be driven into the horizontal joints, commencing at the top and going downwards; this process is then repeated from the bottom upwards, taking the vertical joints at the same time, and is continued until an iron chisel similar to that before described cannot be driven in between the tubbing plates.

The plug hole I, Fig. 4, Plate 46, in the centre of each plate, is left open until the wedging is completed; oak plugs are then driven tightly in, commencing with the bottom plates and proceeding upwards. This must not be done more rapidly than the rate at which the water will rise at the back of the tubbing, in order to afford every opportunity for the escape of air or gas: a sudden closing up of all the holes has been known to cause a pressure so sudden and violent as to fracture some of the plates, which have had to be replaced. In some districts it is not unusual to connect a small pipe with one of the plug holes, and take it up the pit side until the top of the pipe is above the level to which the water will rise, in order to permit the escape of confined air or gas; but this has never been done at any of the collieries which have come under the writer's supervision.

The deepest tubbing with which the writer has had to deal is at the Baddesley Colliery near Atherstone, where a spring of water was found at 220 yards from the surface. The pressure of water at this depth was of course very considerable, and rendered great care requisite in putting in sound castings and fixing them accurately and securely: the tubbing plates used were 15 inches in height.

The upper part of these shafts had been tubbed continuously from 140 yards in depth up to 50 yards from the surface, making a column of tubbing 90 yards in height. The sinking then proceeded dry for 80 yards deeper, when the spring above mentioned was met with. This occurrence had not been at all anticipated, as it is very unusual in the midland counties to find springs of water much below 150 yards in depth. The feeder being too powerful to be drawn out by barrels entailed considerable inconvenience and expense in the arrangements for pumping.

There were two shafts, each 7 feet in diameter, and 12 yards apart, placed in front of the permanent winding engine, which was a vertical high-pressure non-condensing engine with a cylinder of 30 inches diameter. The pit nearest to the engine was called No. 1, the other No. 2. The water out of No. 1 pit was delivered into an offtake drift 40 yards from the surface, which had been driven up from

a valley for more than 600 yards. This gave a height for the water to be pumped at first of 180 yards, without it being known to what depth the spring might continue. As this was of course too much for one lift of pumps, and as the shaft was too small to admit two lifts of 13 inch pipes and give space at the same time for drawing out the sinking dirt, a rather complicated arrangement of pumping gear was rendered necessary.

A standing set of pumps was fixed in a cistern in No. 1 shaft nearly 20 yards below the wedging crib of the upper tubbing, or about 160 yards from the surface. It was deemed necessary to go this distance below before driving through into No. 2 pit, to prevent all risk of letting down the tubbing. This standing set was 117 yards long with a 12 inch working barrel.

In No. 2 pit was hung a lift of 13 inch pipes with a 12 inch working barrel, and commencing with a length of about 67 yards. These pumps were hung in screws, which were attached to wooden rods 6 inches by 7 inches square, the lower ends of the rods being connected by strong ironwork to the suction nozzle of the pump, which was made of a suitable shape for the purpose.

By a series of quadrants or T bobs, pumping beams, and connecting rods, motion was communicated to the pump rods from a crank on the end of the flywheel shaft, which projected through the engine house at a considerable height above the ground. This would not have been the mode adopted, had the existence of the deep spring been at all expected; but under all the circumstances it answered exceedingly well, and accomplished the desired object by keeping the shaft clear of water until the whole of the water was effectually tubbed back.

The 90 yards of tubbing which had been put in the upper part of the shafts was divided into four lengths, of 35, 29, 18, and 8 yards respectively, commencing from the top. At each of the three upper lengths one wedging crib was put in; and at the bottom two metal cribs each 9 inches deep were placed upon an oak crib 6 inches thick.

In pinning up one series of tubbing plates to a wedging crib above, very great care is requisite in order that the upper tubbing

may not be disturbed; the stone must be taken out in short lengths, and a segment put in before the stone to admit the adjoining segment is cut away.

It will very much facilitate the operation of fixing the tubbing in the pit, if the iron wedging crib be laid upon a level and solid place upon the pit bank, and fitted with the deal sheathing to the proper size of the pit; an iron rod turning upon a pivot fixed in the centre of the circle can be used as a template. Upon the crib the various segments should be fixed, and any untrue castings rejected. When the first ring of segments is fitted, the plates composing it should be marked A 1, A 2, A 3, &c., to the whole number in the ring; the second ring of segments should then be placed upon the first ring, and when fitted marked B 1, B 2, B 3, &c.; and so on for every ring, segment by segment. When three or four rings have been thus fitted, they are taken down, the uppermost laid upon the crib, and a similar number of rings fitted above it, each segment being lettered and numbered; and so on with the whole of the tubbing.

The soundness of each casting should be carefully tested with a heavy hand-hammer having a diamond point, and all those rejected that show symptoms of honeycomb or other defects. Too great attention cannot be paid to this, the value of a rejected casting being very small as compared with the loss of time and money that may arise from the failure of an unsound segment fixed to resist a great pressure of water.

In the case of a shaft being required as an upcast, and where the effect of the corrosive vapours given off from the coal consumed in the ventilating furnace would be prejudicial, it is better to set the tubbing back sufficiently to admit of a course or more of brickwork being built in front of it to protect the iron. The writer has seen iron not so protected which has assumed the appearance and character of carburet of iron or plumbago for some depth from its surface, and was soft enough to be cut with a penknife without turning the edge.

It has been attempted in some instances to use tubbing formed of cast iron cylinders of the diameter of the shaft and 4 or 5 feet in height, with flanges inside and boltholes so that they could be screwed together. This has been found to be a very imperfect and unsatisfactory

kind of tubbing, and will not bear the slightest comparison with tubbing composed of segments and wedged in the manner previously described. The large cylinders are very unwieldy, and present great difficulties in passing the pumps and pumping gear at the pit top. In addition to this they do not by any means afford such facilities for repair: if a fracture occur to a single segment, it can be replaced without much difficulty, which would not be the case if a cylinder failed; and practice has shown that wedged tubbing can be made much tighter than that which is bolted.

With regard to the requisite strength of cast iron tubbing at various depths from the surface, the following are the results of some calculations made by Mr. Atkinson of Durham, one of the inspectors of coal mines, which arose out of a recent discussion at the North of England Institute of Mining Engineers upon the relative merits of cast iron and cement to withstand a pressure of water. For a shaft 10 feet in diameter he estimates the thickness of metal in the tubbing should be

at a depth of 20 yards,		0·132	inch thickness of metal.
40	...	0·264	
60	...	0·396	
80	...	0·528	
100	...	0·660	
120	...	0·798	
140	...	0·936	
160	...	1·068	
180	...	1·206	
200	...	1·362	

In practice however it is not found desirable to use at any depth tubbing of a less thickness than half an inch, in order to prevent risk of fracture from blows in the shaft arising from banging of the tubs or fall of coals from the pit bank. It is also better to use tubbing thicker than the theoretical strength, to provide for waste by corrosion. It may therefore be considered that in a shaft of 10 feet diameter the thickness of tubbing should vary from $\frac{5}{8}$ inch at 20 yards deep to $1\frac{1}{2}$ or $1\frac{3}{4}$ inch at 200 yards deep: the thickness varying in different shafts directly in proportion to the diameter of the shaft, a shaft 16 feet in diameter for instance requiring at an equal depth tubbing twice as thick as that in an 8 feet shaft.

In putting in tubbing at great depths, the writer recommends that the height of the segments should be reduced, as by that means the flanges are brought nearer together; 15 inches is a very convenient height for such cases, 24 inches and 30 inches being used at smaller depths.

The value of tubbing in shafts depends to a considerable extent upon the depth of the shafts. If the feeders of water are found only a short distance above the seam of coal, it will be quite useless to tub back the water in the shaft, because as the coal workings proceed the roof will break down and the water will find its way into the workings. In determining whether to use tubbing or pump the water, very much depends upon the character of the strata that intervene between the water and the coal. The writer knows cases in Derbyshire where shafts 120 and 140 yards in depth are tubbed, and most successfully; in both cases the bottom of the tubbing is 70 yards from the surface, leaving only 50 and 70 yards respectively as the distance of the lowest feeders of water above the coal. The thickness of the seam of coal worked is from 5 to 7 feet, and the workings have extended over a very large area without letting water down.

Tubbing has been very little used in Yorkshire; but there can be no doubt it might have been successfully employed in many instances, and that it will become generally adopted in sinking deep shafts. In Northumberland, Durham, and Lancashire, almost every shaft that has been recently sunk to a considerable depth has been lined with cast iron tubbing where passing through feeders of water. A very important operation of this kind has been performed with great success at Shireoak Colliery near Worksop, in a deep pit belonging to the Duke of Newcastle, and a detailed description of the sinking of this colliery would prove interesting to mining and mechanical engineers; since it is particularly to be desired as advantageous to all parties that all matters appertaining to the very important question of coal mining upon a large scale should be made generally known.

Mr. Brown showed a model of the tubbing, explaining the manner in which the several segments were put together so as to break joint in each successive course, with a layer of wood ⅜ inch thick laid between the courses of tubbing. He stated that metal tubbing was not much employed at present in Yorkshire, but was in general use in Northumberland, Durham, and Lancashire; and good tubbing was now becoming of great importance from the necessity of sinking deeper shafts, on account of the coal seams near the surface getting exhausted.

The Chairman enquired whether the quantity of water in the shaft was found to increase at greater depths.

Mr. Brown replied that was not usually the case, and it was generally sufficient if the tubbing were carried down about 100 or 120 yards only; but occasionally the shaft required tubbing as deep as 200 or 300 yards from the surface.

The Chairman asked whether any coating with paint had proved a sufficient protection for the cast iron tubbing from corrosion.

Mr. Brown replied that sometimes the tubbing was merely painted or coated with oil, but this was not sufficient to protect the metal from corrosion by the smoke in the upcast shaft, and in that case therefore the segments were set back about six inches on each side of the shaft and lined with brickwork.

Mr. C. Cochrane thought that when the tubbing was protected by being lined with brickwork it would be difficult to find out any leak that might occur behind the brickwork, and it might be necessary to pull down a quantity of the lining to get at the leak.

Mr. Brown said there was certainly that objection to lining the tubbing with brickwork, and the question therefore was whether it was a less evil to run the risk of the tubbing being corroded, or to incur the difficulty of finding out a leak if one took place. In general however the tubbing could be put together tight enough to prevent any leaks occurring, if care were taken also to see that all the castings were thoroughly sound before being put in their places.

The Chairman enquired whether a leakage generally increased after it had broken out.

Mr. Brown replied that the leakage did not increase, and would sometimes take up completely after a time, so that it was best to wait

awhile when a leak had broken out, before beginning to search for it. When the leakage did not stop of itself it was not necessary to take out the segment of tubbing, but the hole could be plugged with wood or the segment wedged up tighter with wood wedges driven in at the joints, so as to be completely water-tight.

Mr. C. Tylden-Wright asked what length of tubbing had been put in at the depth of 220 yards at the Baddesley Colliery in Warwickshire mentioned in the paper; and what was the pressure of the water behind the tubbing.

Mr. Brown said it was 7 or 8 years ago that the tubbing was put in, and he believed the length was 10 or 15 yards. That was the greatest depth at which he had seen tubbing put in a shaft hitherto, and the pressure behind the tubbing was the greatest that he had yet encountered, amounting to nearly 300 lbs. per square inch; the diameter of the shaft was 7 feet inside the tubbing. There were no pipes to the surface of the ground for taking off the gas that accumulated behind the tubbing, but the vent holes left in the segments were plugged up one after another as the water rose, the top holes being kept open as long as possible to ensure the whole of the gas being allowed to escape. He enquired whether any trouble had been experienced in the recent sinking at the Shireoak Colliery near Worksop from the sheeting being blown out by the gas; and what length of tubbing had been required in that case.

Mr. C. T. Wright replied that at the time of putting in the tubbing at the Shireoak Colliery the wood packing had been blown out of the joints by the gas and the tubbing itself disturbed, from want of vent pipes to carry off the gas from behind the tubbing; but these had since been added in the lower lengths of the tubbing, and it had now stood for two years without giving any further trouble. There were two pits sunk at that colliery, each 12 feet diameter inside the tubbing, which was lined with 3 inches thickness of brickwork to protect it from corrosion, reducing the working diameter to 11½ feet. The tubbing extended a total length of 170 yards from the surface in each pit, and consisted of eleven lengths, the total weight of cast iron used being more than 1200 tons. The pressure of water behind the tubbing was about 190 lbs. per square inch at the bottom.

Mr. Brown enquired what was the nature of the ground through which the sinking was made.

Mr. C. T. Wright replied that the pits were sunk for the purpose of winning the Top Hard coal, which lay at a depth of about 515 yards at that place. The sinking passed through the magnesian limestone for a distance of 36 yards, and afterwards through a very hard gritstone 66 yards thick, in which were the largest springs of water at about 25 yards below the limestone. It had been hoped at first to keep the shafts clear of water by pumping, and two sets of 14 inch pumps were employed for the purpose; but the great feeders of water here met with, yielding as much as 500 gallons or 2¼ tons of water per minute in the two pits, rendered it impossible in regular work to keep the water down by the pumps, and it was therefore necessary to have recourse to tubbing. The rock yielding the water however was so strong that the coal below could have been worked away to within 40 yards of the bottom of the tubbing, without any fear of the rock falling in and letting the tubbing come down.

Mr. J. Fernie asked what was the thickness and size of the segments in the tubbing at Shireoaks, and whether any of them had broken.

Mr. C. T. Wright said that each course of tubbing was 12 inches high, and there were 12 segments round the circle, each weighing 3½ cwts. The thickness of metal was 1⅛ inch at the bottom of the shaft, and each segment was strengthened by three ribs on the back: a lighter description of tubbing only ⅝ inch thick, and each course 24 inches high, was used in the upper part of the shaft for passing through the magnesian limestone. Several of the segments had broken from being wedged in too tight, all of which broke through the centre plug hole; these had to be taken out and replaced, and on one occasion 7 yards' length of the tubbing had to be taken out for replacing the broken segments.

Mr. Brown enquired how far the tubbing was made to extend at top and bottom beyond the strata yielding the water.

Mr. C. T. Wright replied that the tubbing extended at the top to the surface level, but at the bottom 1 foot below the point where the water was met with was enough, because the rock at that part

was very hard and impervious to water. The joining of each length of tubbing to the length above was made by casting matching plates of the size required just to fit in the space left, instead of filling it up with an oak crib, as he considered wood was too soft to be employed permanently in tubbing on a large scale.

Mr. H. Maudslay enquired whether compressed oak had been tried for wedging up the segments.

Mr. C. T. Wright had not tried it, but pitch pine was used in preference to oak for the packing and wedging between the segments, as containing more gum and swelling to a greater extent, so as to tighten the segments more effectively.

It was most important for metal tubbing in shafts that some effectual means of preventing corrosion should be adopted, as it would be a very serious and dangerous operation to take out any segment under such a great pressure as there was behind the tubbing at Shireoaks. At present the tubbing had stood perfectly well, being lined with 8 inches thickness of brickwork; but the pressure pipes passing up the shaft from the tubbing to the surface became greatly corroded, and both pipes and taps had occasionally to be replaced. The main pipes were strong cast iron gas pipes of 3 inches bore, with gas pipes of 1¼ inch bore to the lower lengths of tubbing, and were well coated with tar; but the corrosion took place mainly on the inside, the water being so corrosive as to eat through the pipes in the downcast shaft; the quantity of water flowing through the pipes in both pits was altogether about 200 gallons or nearly a ton of water per minute.

Mr. H. Maudslay suggested that a good plan for coating iron with tar was to heat the iron to a black red heat and then plunge it while hot in the tar; he had seen some gas and water pipes intended for works in France which had been coated in that way, and the surface of the iron was then clean for receiving the coating of tar.

Mr. C. Cochrane said that they had for many years made a regular practice at their works at Dudley of coating cast iron pipes both outside and inside with a mixture of pitch, naphthaline, and oil, kept hot in a tank; the pipes were dipped in it while nearly red hot, after having been previously cleaned and dressed, and were then taken

out and left to dry, the surplus draining off them. This preparation had been used extensively for coating water pipes, and formed a very efficient and durable protection to the metal, resisting corrosion for many years. He had proposed applying it to the tubbing of their pits in the north of England, but had not yet tried it for that purpose.

Mr. A. B. Cochrane said that water pipes coated in that way had now been laid 10 or 12 years in Manchester, and were found to be thoroughly preserved from corrosion. The coating looked like a black varnish, and adhered very closely to the metal; and when the pipes were properly coated before the iron had become at all rusted they continued after many years as good as when laid down. In some pipes that he had made for the Melbourne water works the coating came off at places where the metal had rusted before it was put on, and they had to be cleaned and done over again; but they stood the voyage and laying in the ground without injury to the coating, and there was no fear of its getting scraped off with moderate care in handling the pipes.

Mr. R. Chrimes had seen the water works pipes at Manchester, 24 inches diameter, and the coating upon them appeared as perfect as when they were laid down. Some of the pipes had been left lying in the street for a year or two before being put in the ground, but the coating remained uninjured notwithstanding the rough usage they had been exposed to. The mixture described seemed to answer well for cast iron pipes, but he believed it did not succeed on wrought iron pipes.

Mr. C. Cochrane suggested that the addition of sulphur would probably render the coating suitable for covering wrought iron.

Mr. J. Manning observed that the process now described was that of Dr. Angus Smith of Manchester, and was extensively used for coating cast iron pipes with complete success. The composition made a covering like a smooth black varnish, and was heated to the boiling point in an open boiler 10 or 12 feet deep, into which the pipes were lowered in bundles while still very hot.

Mr. H. Woods remarked that a coating of glass enamel made a very perfect protection from corrosion; he had tried it for wrought

iron pipes from 2 to 5 inches in diameter in a large brewery and it answered admirably; and he had seen pipes up to 3 inches diameter which had stood a very high pressure without the enamel being affected.

Mr. A. B. Cochrane thought the cost of that process was too great to allow of its being much used for ordinary work, and the glass would not bear the rough work it would be exposed to in pits, but would soon get chipped off. The mixture of pitch however seemed applicable with much advantage for cast iron tubbing; the segments of the tubbing might be dipped in it before the iron got cold after casting, and the cost of the process was moderate.

Mr. E. Riley thought the most effectual protection for wrought iron against corrosion was a coating of carbon deposited on its surface, which was accomplished by cleaning the surface of the iron and burning oil, tallow, tar, or some other hydro-carbon upon it. He had found iron thus treated resist the action of acid fumes for a long period.

The Chairman remarked that the subject of the paper was of interest not only to the owners of mines but to all persons residing near, since the effect of the shaft would be to drain all the springs in the neighbourhood if it were attempted to keep down the water by pumping; and it was therefore very desirable that the water should be efficiently stopped back by tubbing, to save the constant waste and expense of pumping.

He proposed a vote of thanks to Mr. Brown for his paper, which was passed.

The Chairman said he had great pleasure in proposing a special vote of thanks to the Local Committee and the Honorary Local Secretary, Mr. T. F. Cashin, for their kindness in making the excellent arrangements for the meeting, which had been attended with such complete success.

The Meeting then terminated, and in the evening a large party of the Members and their friends dined together at the Cutlers' Hall.

On the following day the Members were taken by the Local Committee an excursion to Chatsworth and the neighbourhood, when, by the kindness and special permission of the Duke of Devonshire, Chatsworth house and grounds were thrown open to them, and the large fountains shown in full operation; and the Members were invited by the Local Committee to a handsome entertainment in the park.

PROCEEDINGS.

7 November, 1861.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 7th November, 1861; Sampson Lloyd, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman referred to the success of the Annual Provincial Meeting held at Sheffield in the summer, with which the members who were present had been much gratified; they had been much interested in the sight of the principal works which were so liberally thrown open for their inspection, with special arrangements for showing the operations on a large scale. The members were most handsomely received and entertained by the Local Committee, who made great exertions to give them a hearty reception on the occasion.

The Chairman announced that the President, Vice-Presidents, and five members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Annual Meeting.

The following Members were nominated by the meeting for the election at the Annual Meeting:—

PRESIDENT.

SIR WILLIAM G. ARMSTRONG, .	Newcastle-on-Tyne.

VICE-PRESIDENTS.

(Six of the number to be elected.)

ALEXANDER B. COCHRANE, .	Dudley.
EDWARD A. COWPER, . . .	London.
JAMES FENTON, . . .	Low Moor.
BENJAMIN FOTHERGILL, . .	London.
SAMPSON LLOYD, . . .	Wednesbury.
HENRY MAUDSLAY, . . .	London.
JOHN PENN, ...	London.
JOHN RAMSBOTTOM, . . .	Crewe.
J. SCOTT RUSSELL, . . .	London.
C. WILLIAM SIEMENS, . .	London.
JOSEPH WHITWORTH, . .	Manchester.
NICHOLAS WOOD, . . .	Hetton.

COUNCIL.

(Five of the number to be elected.)

ALEXANDER ALLAN, . . .	Perth.
FREDERICK J. BRAMWELL, .	London.
WILLIAM E. CARRETT, . .	Leeds.
GILBERT HAMILTON, . .	Soho.
GEORGE HARRISON, . . .	Birkenhead.
THOMAS HAWKSLEY, . .	London.
EDWARD JONES, ...	Wednesbury.
JAMES SAMUEL, . . .	London.
CHARLES P. STEWART, . .	Manchester.
EDWARD WILSON, . . .	Worcester.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Charles Edwards Amos,	London.
Thomas Dixon,	Low Moor.
Thomas Fearnley,	Bradford.
Joshua Field, Jun.,	London.
William Bailey Hawkins,	Pontypool.
Samuel Waite Johnson,	Manchester.
Gustavus Natorp,	Sheffield.
John William Naylor,	Leeds.
Walter Henry Scott,	Wolverton.
John Shepherd,	Leeds.
George Taylor,	Leeds.
Robinson Thwaites,	Bradford.
William Yule,	St. Petersburg.

GRADUATE.

Henry Charles Middleton,	Birmingham.

The following paper was then read :—

DESCRIPTION OF A RIVET-MAKING MACHINE.

By Mr. CHARLES DE BERGUE, of Manchester.

The main feature of this machine consists in its making rivets by a continuous motion, and in its compactness and simplicity of action. The construction of the machine is shown in Plates 47 to 51. Fig. 1, Plate 47, is a front elevation of the machine, showing only the heading arrangement. Fig. 2, Plate 48, is a transverse section, showing the cutter for cutting the blanks previous to heading. Fig. 3, Plate 49, is a sectional plan. Fig. 4, Plate 50, is a side elevation; and Fig. 5, a longitudinal section.

The disc A, Fig. 1, Plate 47, revolving on a horizontal shaft carries the dies for holding the blanks to form the rivets, of which there are eight in the circumference, marked BB in Figs. 6 and 7, Plate 51, revolving in the direction of the arrow. Figs. 8 and 9 show enlarged sections of the dies. The cast iron header C, shown enlarged in Figs. 10 and 11, by which the heads of the rivets are formed, is carried by the crank D fixed on a second horizontal shaft, revolving eight times for once of the disc A, and so geared with it by the toothed wheels EF, Fig. 3, as to coincide exactly with the eight dies as they successively pass before the header C at the moment of its full stroke towards the disc. At this time the disc carrying the dies and the header are for a moment travelling together. The end of the bar carrying the header C slides in a slot G in the ring H, which revolves freely upon the centre pin I of the disc. The inner half of this ring H is turned eccentrically, as shown in Figs. 6 and 7; and upon it a loose ring K is placed, which takes the thrust of the pins for holding up the rivets during the heading and forcing them out of the dies when completed. The eccentric is held in a fixed position, or nearly so, by the end of the header bar sliding through the slot G,

the eccentricity being set not quite opposite to the point where the heading takes place, so that the moment the header has left the die, the eccentric begins to act in forcing the rivet out. The loose ring K always moves with the pin which holds up the rivet while the heading is being performed and also while forcing out the rivet, and thus throws the wear upon the whole surface of the eccentric, instead of confining it to the portion directly under the header.

To prevent the possibility of accident to the machine from blanks being put into the dies too cold or too large in size, the header C is supported behind by a small crushing piece of cast iron L, shown enlarged in Figs. 12 and 13, Plate 51, which lies free in a recess in the header bar. This crushing piece is made of such sectional area as to resist the usual crushing strain required for heading a rivet, but to yield by crushing if by any accident a cold rivet blank or any other unyielding substance should get between the header and the die, forming a complete protection against injury of the machine by overstrain in working. Fig. 13 shows the manner of fracture of one of the crushing pieces.

During the time of the header being in action, the motion of the header and the die as governed by the toothed wheels E and F would not be perfectly coincident, except at the beginning and the end of the heading process. At the point where the process commences, which is a point adjustable at option, the centre line of the header as carried forward by the toothed wheels coincides with the centre line of the rivet to be headed; then proceeding in the direction of the rotation, the rivet over-runs the header slightly, and again exactly coincides with it when on the centre line or line of greatest pressure: after which the reverse action takes place as the header recedes from the die. The motions of the header and the die are however made perfectly coincident throughout by means of a steel pin M, Fig. 3, Plate 49, inserted in the header bar alongside of the header; and eight corresponding holes N to receive this pin are bored in the circumference of the disc, Figs. 3 and 4, side by side with the holes which contain the dies. The pin M enters the hole in the disc at the point where the heading process commences; and the teeth of the driving

pinion E are at the same time partially cut away, so as to clear the teeth of the larger wheel F while the pin is in action; and then as the pin leaves the hole in the disc, the teeth of the pinion again take up the driving action and continue the movement of the disc. Thus the die is carried forward during the heading process by the pin M, independently of the teeth of the pinion, which are not required at that part of the rotation for working the machine; but they are still retained in order to keep the wheels in gear throughout the entire revolution, and are left strong enough to carry on the motion safely even without the pin M.

The bars for making the rivets are heated in a furnace alongside the machine, and are then cut off to the required lengths by a lever cutter O, Fig. 2, Plate 48, driven by a double cam on the heading shaft, thus allowing two lots of rivets to be cut for one rivet made, and so giving time for changing the bars while still a sufficient supply of blanks is always kept cut; 4 to 6 blanks are cut off in each batch, about 10 bars being kept in the furnace at once. The blanks are fed into the dies by two boys, a third boy doing the cutting. The lengths to be cut off are regulated by an adjustable bar P, Fig. 2, sliding upon a pin and moved backwards or forwards by a screw.

The first motion is given to the machine by a belt upon the pulley R, Fig. 3, Plate 49, and thence through the pinion S and spur wheel T. The framing at the front of the machine is made exceedingly strong, for resisting the strain of tension thrown upon it during heading; while the back frame on the contrary is arranged to receive the compression strain of the tail ends of the shafts.

The machine is placed close by the side of the furnace, so that the heated bars have only to be carried about 2 feet distance from the furnace mouth to the cutter, and the ends cut off fall into a trough, down which they run to a convenient position for the boys who feed the dies. The finished rivets fall out below the disc into a truck placed to catch them, and are thence wheeled away. The machine is speeded according to the size of rivets to be made: thus for 1 inch rivets the disc revolves 4 times per minute, making 32 rivets per minute; and for $\frac{7}{8}$ inch rivets the disc revolves 5 times per minute, making 40 rivets per minute.

The objects aimed at in applying machinery to rivet making are, more uniform and perfect manufacture of the rivets, and a more rapid production than by hand making; together with independence of the risks of delay in the supply by hand work when large quantities are required. But from the simple nature of the work, and the small margin for economy in manufacture by the application of machinery, only a very simple and durable machine is suitable for the purpose.

The advantages found in the machine now described are that by the continuous motion a saving of time is effected, and a larger quantity of rivets are produced in a given time; while the shocks and concussions attendant upon stopping and starting the motion, with the consequent jar and destructive wear and tear, are avoided, increasing the durability of the working parts. The use of the crushing piece also behind the header serves as an effectual safeguard against breakage, and prevents the strain that can be put upon the machine ever exceeding the intended limit, which for making 1 inch rivets is taken at about 20 tons. The whole machine also lies in a compact and convenient form, taking up a space of about 5 feet by 9½ feet, as shown in the plan, Fig. 3, Plate 49; and only about 8 feet by 9½ feet total space including the heating furnace.

The heating furnace is of a compact and convenient construction, 8 feet long by 2½ feet wide in the body, with the fire at the back end. The flame passes over the bars to be heated, and down a flue at the front end, just within the drawing-out door, thus avoiding any cooling effect upon the bars when the door is opened, and keeping up a very uniform heat.

Mr. Joy showed specimens of the rivets of different sizes made by the machine, and of the heading dies both new and when worn out; also of the safety crushing pieces, whole and broken.

The Chairman observed that there were many difficulties to be overcome in applying machinery satisfactorily to the manufacture of rivets, and though several machines had been constructed for the

purpose, few had proved durable in the working parts or perfect in the mode of making the rivets. The present machine though not new in some of its parts appeared in others to present novelties deserving of consideration. He enquired how long the machine had been in operation, and what had been the wear and tear of the working parts, as that was the main point in all such machines, which would often work well for a time, but afterwards were always getting out of repair and requiring renewal.

Mr. Joy replied that they had had two machines at work for about two years, and a larger machine as shown in the drawings for about one year. No wear was yet perceptible on the working parts, excepting the dies and headers, which of course had to be renewed for both hand and machine work in proportion to the amount of work done. The two horizontal shafts in the machine had been taken out and examined, and were found entirely free from wear. The bearings and shafts were entirely cast iron, got up very true, and with such a large extent of surface that the pressure was never enough to begin wearing the metal. When the first machine was made, a heart-wheel or cam was employed for pushing the rivets out of the dies; but the ends of the jingle pins grinding against it under the heavy pressure of forcing out the rivets caused such an excessive wear at that part that after a short time the cam had to be taken out for repair, and they had turned it down circular as an eccentric, and put on a loose ring as a ready means of repairing it. This had proved so entirely successful in removing the wear that it had been permanently adopted in the machines; the head of the pin seized the surface of the ring under the severe pressure of forcing out the rivet, and carried the ring round with it, so that there was no wear between the head of the jingle pin and the ring, while the large surface of the eccentric allowed the ring to slip round it freely without sensible wear. The cast iron crushing piece behind the header gave way occasionally with a sharp report in the ordinary course of working, particularly on first starting, before the machine got warmed into its usual working condition, the hot blanks probably being too much chilled in the cold dies; but a supply of crushing pieces was kept on hand and a fresh one put in whenever required.

The CHAIRMAN asked how long the cast iron dies lasted, and whether they were chilled in casting, or were simply plain castings.

Mr. JOY replied that the dies usually lasted two or three days and sometimes as much as six days. The cast iron was toughened by a mixture of wrought iron scrap, and the dies were merely cast in sand and not chilled ; the die hole was drilled afterwards out of the solid, and a groove was slotted in the side of the die to receive the tightening key for holding it in the disc, but no fitting was required for fixing the dies in their places. They had tried casting the hole in the die by means of a hollow steel spindle with water running through it, so as to chill the interior of the hole ; but this did not succeed at all, and a sand core had also been tried, which was more nearly successful ; the simplest and best way however was to cast the die solid and drill the hole afterwards. After being worn out for one size, the dies were bored out again several times for larger sizes of rivets, before being completely worn out. The header was also made of cast iron, not chilled : cast iron was found to stand better than steel for the header, for a steel header had been tried but it cracked all to pieces after heading a few rivets, and steel was of no use for such purposes.

Mr. E. A. COWPER had also found cast iron stand best for a similar purpose in a large hydraulic punching press for punching out red-hot the links for suspension bridges : a link 7½ feet long and 1 foot 8 inches across the eye was punched out of 1 inch thickness of metal by a cast iron punch and die, when the metal was red-hot. He had tried steel punches also, but they did not stand for punching more than half a dozen links and were then spoilt, as the steel would not stand the frequent heating by contact with the hot iron without cracking. Ultimately cast iron punches and dies alone were used, and lasted each about a month in punching out the links, punching in that time probably 200 links. He enquired whether there was any circulation of water in the rivet machine for keeping the dies cool when at work.

Mr. JOY replied that there was no circulation of water in the dies, but two streams of water played over the disc as it revolved to keep it cool ; it must not be too much cooled however, otherwise the machine did not work well, and the crushing piece got broken frequently ; the

machine was allowed to get about as hot as the hand could bear, and then it worked well.

Mr. E. A. Cowper enquired whether any of the machine rivets had been cut down longitudinally through the centre, and the surface then polished and browned with acid, to show the direction of the fibre in the rivet head. In hand-made rivets the smith first jumped up the end of the blank, thereby spreading over the fibre all round, before shaping the head; and he thought the fibre might be rather better laid over in that way than in the machine rivets. He asked whether the comparative strength of the machine rivets and those made by hand had been ascertained.

Mr. Joy had not tried the comparative strength of the machine made rivets, nor examined the section in the manner suggested for showing the fibre; but as a means of showing plainly each stage of the heading process he had tried in the machine a series of blanks too short to make the rivet, increasing successively in length up to the full size. This experiment showed that the iron was first bulged out all round close to the die, as soon as the header began to press upon it; and this bulging out gradually increased in extent as the length of the blank was increased, so that in the complete rivet the head was made by the fibres of the iron being bent over all round, and had therefore great strength and solidity. This was further shown by tearing off some of the rivet heads, when the fibre of the iron was found to be all broken through transversely, in consequence of the direction it had assumed by being bent over to form the head. The great advantage in making rivets by machinery was that they were all exactly alike; and this uniformity was effectually attained in the present machine, and could not be secured except by the use of machinery.

Mr. E. Jones thought the strength of rivets depended mainly on the quality of iron they were made from, and that there was not much difference in strength between hand and machine made rivets from the same quality of iron, if equal care were taken in the manufacture.

The Chairman asked what was the relative cost of production in making rivets by the machine and by hand, and the capability of the machine as to extent of manufacture.

Mr. Joy replied that the relative cost of making the rivets depended mainly on the total quantity to be made: if only a small quantity were wanted, hand work was undoubtedly much the cheapest; but if a large quantity, then the machine would be the cheapest. The number of rivets made per day by the machine depended much on the form of the head: an ordinary snap or semicircular head was the best to make, but full large heads with flat tops were most difficult, requiring so much material to be crushed up to form the head; and some ¾ inch rivets that they had made with large heads took as much as 2⅛ inches length of body to make the head. Any form or size of head however could be made in the machine by simply changing the header for one of the required shape. The number of rivets made per day by the present machine in regular work was about as follows:—

⅞ inch	rivets	3	inches long	when finished,	30	cwts. or	4000	rivets per day.
¾	"	3	"	"	25	"	6500	"
⅝	"	2⅛	"	"	20	"	9000	"
½	"	2⅛	"	"	15	"	12000	"

The Chairman enquired what was the cost of the machine.

Mr. Joy said a machine of the size shown in the drawings cost about £300, including an apparatus for moulding and casting the dies.

The Chairman moved a vote of thanks to Mr. De Bergue and Mr. Joy for the paper, which was passed.

The following paper was then read:—

ON AN APPLICATION OF GIFFARD'S INJECTOR AS AN ELEVATOR FOR THE DRAINAGE OF COLLIERY WORKINGS.

By Mr. CHARLES W. WARDLE, of Leeds.

The apparatus described in the present paper was applied by the writer to meet the special requirements of the working of a portion of the Kippax Colliery near Leeds, where it has been in constant operation for the last eight months. It is a self-acting apparatus for raising the water for drainage of a portion of the pit workings, and has completely answered its intended purpose; and a similar application may be of service in other special cases where the cost of fuel is not a consideration, but a simple and inexpensive apparatus is required not needing attendance in working. In the present case a small portion of the colliery, about 2 acres, was required to be worked out, which was lying below the drainage level of the pit, and at a considerable distance from the shaft; and as the extent to be worked was so limited, it did not allow of the erection of a special pumping engine, and hand pumping was employed to raise the water a height of 27 feet to the upper level which was drained by an engine. This mode of draining was continued for two years, two shifts of two men each being employed constantly at the last with a 3½ inch pump; but they were not able to keep down the water in the lower workings as it had increased in quantity, and some other less expensive and more efficient means was required to enable the rest of the coal to be worked out.

An application of a Giffard's injector as an Elevator was proposed by the writer for this purpose, and was carried out as shown in Plates 52, 53, and 54. Fig. 1, Plate 52, shows a general plan of the colliery, with the position of the elevator and the steam and discharge pipes; and Fig. 2 is a general section taken along the line of the steam and discharge pipes. The steam pipe, shown by the dotted

black line, is a wrought iron pipe of 1½ inches bore with screwed joints, carried 60 feet from the steam boiler to the shaft, descending the shaft 243 feet, and then passing along an inclined heading 730 feet long and falling 27 feet to the elevator, which takes the water at that level and discharges it by an iron pipe of 2 inches bore, shown by the full black line, carried a distance of 300 feet up another inclined heading to the main drainage level at a height of 27 feet above.

The elevator A, Fig. 3, Plate 53, is fixed in a cistern B sunk in the water, so that the inlet pipe C is at the water level. The elevator is shown in section one third full size in Figs. 5 to 7, Plate 54, and is a modification of a small sized injector, made in the simplest form for the sake of cheapness. It consists of a fixed steam jet D, with brass nozzle E of $\frac{5}{16}$ inch aperture, fixed in a cast iron casing A without any means of altering the position, with the steam pipe F connected at the top and the discharge pipe G at the bottom, the whole being closed without any overflow; the discharge aperture of the casing A is tapered gradually in both directions to ⅜ inch bore at the throat H.

In consequence of the great length of the supply steam pipe, 1030 feet from the boiler to the elevator, provision has to be made for constantly carrying off the condensed water deposited in the pipe, in order to ensure the elevator being constantly supplied with tolerably dry steam, as the entrance of water with the steam would stop its action. This is effected by passing the steam through the top of the depositing box I, Fig. 3, Plate 53, 10 inches diameter and 3 feet deep, from the side of which the water flows off into the self-acting water trap K, shown in section one third full size in Fig. 4. The water trap is a closed cylinder containing a copper cylindrical float L, 8 inches diameter and 8 inches deep, open at the top, and guided by a centre tube sliding up the small pipe M. This pipe M is prolonged outside over the side of the vessel K, and serves as the discharge for the accumulated water; its lower end is closed by a small conical valve N fixed on the bottom of the copper float, which keeps it closed until the water has accumulated in the trap outside the copper float so much as to flow

over its sides at the top, and to fill up the interior of the float so that it is overweighted and sinks; the conical valve N being then opened, the water contained in the float is expelled through the discharge pipe M by the pressure of steam upon its surface, and the float again rises and closes the pipe ready for another charge.

The temperature of the heading through which the steam pipe is carried is about 72° Fahr., and the steam pipe is clothed for about one third of its length, throughout the portion from the boiler to the bottom of the shaft, with a coating of tarred felt wrapped round it, and the remaining portion in the pit is wrapped with haybands. But with the great length of the pipe, 1030 feet, and its small diameter of 1½ inches, this clothing is not sufficient to prevent a very considerable amount of condensation taking place; and there is a constant discharge from the water trap of about 3 gallons per hour during the working of the elevator, a discharge taking place at successive intervals of about a quarter of an hour. This serves quite efficiently for keeping the steam supplied to the elevator free from water, and the elevator continues working uninterruptedly for many hours together; when the supply of drainage water is sufficient, it works continuously day and night without any stoppage. It does not require any attention in working, and is started simply by turning on the steam at the boiler at top, when the elevator starts working at once. There is no valve in the discharge pipe, so that the pipe becomes emptied each time that the elevator is stopped working, the water running back through the instrument and out at the inlet pipe. There is consequently no pressure of water to be overcome at starting, and the elevator always starts working at once, when the supply water is up to the level of the inlet, but not if the water has to be lifted in the inlet pipe. All that is required in starting the elevator afresh is to blow through by turning on the steam for two or three minutes to warm the pipes; and then after shutting off the steam for a few seconds to allow the condensed water to drain off, the apparatus is started at once in full work by turning on the steam again.

When the apparatus was first set to work, the depositing box had not been applied, and the action of the elevator became soon stopped by an accumulation of rusted scales from the interior surface of the

wrought iron steam pipe. But the addition of the depositing box completely removed this difficulty, and the box has never required opening during the eight months it has been in work.

The pressure of steam at which the elevator is regularly worked is 34 lbs. per square inch above the atmosphere at the instrument, and it will keep working down to about 28 lbs. pressure when it stops. A difference of pressure of 13 lbs. per inch constantly exists between the two ends of the steam pipe, the working pressure in the boiler being 47 lbs. per square inch, in consequence of the large condensation in the pipe and the resistance occasioned by its small diameter. The elevator accordingly stops working when the boiler pressure is lowered to about 40 lbs. per inch.

The temperature of the delivery water at the further end of the discharge pipe is 94°, that of the supply water being 58°; and the quantity discharged by the elevator is 780 gallons per hour raised a height of 27 feet. The consumption of rough coal slack for generating the steam supplied is about 1½ cwt. per hour; the boiler is a plain cylindrical one, 4 feet diameter and 30 feet long, with oven setting, and supplies steam also to the winding engine for the pit; but its consumption of fuel was taken separately in the night when supplying steam to the elevator alone, the fuel being only refuse slack from the pit of a very inferior and dirty description, for which there is no other use. Consequently the only expense incurred in the drainage of the workings by the elevator, besides the little extra wear of the boiler, is the cost of attendance for firing the boiler about once per hour during the night, when the winding engine is not required to be worked. There have been no expenses for repairs of the apparatus, the elevator never having been opened since first put in its place, except on the occasion previous to adding the depositing box soon after starting, as before mentioned.

The following are some of the cases where the elevator seems to be applicable with advantage. Where fuel is very cheap: as at a pit's mouth, where the small coal is sometimes burnt simply to get rid of it. Where steam is blowing to waste: as in forges at night, when the

production of steam continues without occasion for its use to the same extent as in the day, and often its blowing off at night is a nuisance; this application of the elevator has been made at Messrs. Sharp Stewart and Co.'s works at Manchester, to fill up the tanks during the night for the day's supply, by making use of the waste steam previously thrown away. Where warm water is of value in the top cistern: as in the case of railway tanks and some factory purposes. Where the supply is seldom needed, and it is desired to save the first cost and maintenance of a pumping engine and also the attendance of an engineman. Where absolute certainty of having the water lifted is required, over and above all considerations of expense: as in keeping the tuyeres of a blast furnace cool; Messrs. Schneider Hannay and Co., of the Ulverstone Hæmatite Iron Works, are arranging to attach elevators to supply the cisterns that furnish the water to the tuyeres of their blast furnaces, being unwilling to depend on their pumps which sometimes fail, whereas the elevator never fails; in this instance also there is an abundance of steam raised by the heat of the waste gas. Where frosts prevail and pumps suffer from ice: the elevator, like the injector, gets itself into working order upon the admission of steam, even when the whole instrument is a mass of ice, the heat of the steam gradually thawing the entire mass without the possibility of doing harm. Where the boiler is far removed from the elevator: as in the case of the drainage of colliery workings described in the present paper; with the elevator no attendant need be sent to start it or mind it.

The Chairman observed that the elevator was a very interesting application of one of the most ingenious inventions, and was likely to be particularly useful for special cases in mining districts, where fuel for raising steam was of so little cost, and the great considerations were simplicity of construction and certainty of action without requiring attendance.

Mr. R. Cunliffe said the elevator was not an economical mode of applying steam for raising water, on account of the water being uselessly heated, but was advantageous in particular cases where economy of power was not the object in view, and where the steam was got without cost from heat otherwise wasted. They were now putting up an elevator for a large paper manufactory near Manchester, where warm water was wanted in the top cistern for the supply of the works, and was used afterwards for the boilers, so that the heat would consequently all be made use of. At Messrs. Sharp Stewart and Co.'s works in Manchester they had had an elevator at work two months, supplied with the waste steam from boilers heated by the flues from the forge furnaces; the boilers kept up a supply of steam at night which was not wanted for any other purpose, and had previously to be left to blow off, making a noise that was a nuisance in a town. Another elevator raised the water a height of 36 feet, and its size was No. 7, of 7 millimetres or ·28 inch diameter in the throat, which was rather smaller than the one described in the paper; with 45 lbs. pressure of steam it delivered 340 gallons in 1 hour to the height of 36 feet, and the temperature of the water was raised 30°, from 74° to 104°. In further experiments they had tried it was found that with a No. 25 elevator, of 25 millimetres or 1 inch diameter in the throat, and with 48 lbs. steam, but only partly turned on, the quantity of water raised to the same height of 36 feet was 640 gallons in 8 minutes, equivalent to 4800 gallons per hour; with the steam full on at 46 lbs. pressure, 565 gallons were delivered in 5½ minutes, equivalent to 6160 gallons per hour: the water was heated only 26°, from 58° to 84°, which was the least rise of temperature that had been observed.

From the trials made with the elevator at Kippax Colliery it appeared that about 1 lb. of pressure was required for each foot of elevation, since the water was there raised a height of 27 feet and the elevator stopped working when the pressure fell to about 28 lbs. per square inch. In France he understood they had tried draining some pits in a succession of lifts with different elevators, each taking its supply water from the delivery of the one below; but such a mode of applying the elevator would be even less economical than the

present, because the instrument would not work if the temperature of the supply water were above 160°, and therefore it would be necessary to let the water be cooled previous to the upper lifts, and a great waste of heat would be occasioned.

Mr. W. Haden enquired what was the size of the steam pipe in these experiments with the elevator raising the water 86 feet high; and whether any difficulty was expected in applying the elevator on a larger scale to drainage.

Mr. R. Cunliffe replied that the steam and delivery pipes were both made 3 inches diameter, in order to work the larger elevator of No. 25 size or 1 inch diameter of throat: the diameter of the steam pipe was however found to be too large, and it was therefore replaced by one of 1⅛ inch diameter, but the delivery pipe was not diminished in size, in order to afford great freedom for the passage of the water. The elevator at Kippax Colliery had only ⅜ inch diameter of throat, and therefore the 1⅛ inch steam pipe gave steam enough to work it, notwithstanding the great amount of condensation in the 1000 feet length of pipe. The small pipe had the advantage that there was very little trouble in making the joints steam-tight, compared with pipes of larger diameter. He thought there would not be any difficulty in applying the elevator on an extended scale for drainage where the cost of steam was not a consideration, since there was no limit to the size of the instrument and the steam pressure might be greatly increased for higher lifts.

Mr. Samuel Lloyd asked whether the boiler described in the paper kept up the supply of steam for the elevator constantly, or whether it was liable to be short of steam after a time.

Mr. Wardle said the steam was easily kept up by ordinary firing, and the same boiler also worked the winding engine as well. In this instance it had been a question whether a small pumping engine should be put down to win the few acres of coal left in the colliery, or whether the coal should be lost, as hand pumping was not sufficient to keep out the water; but the elevator afforded the means of getting all the coal out, with the least possible cost of apparatus and without requiring attendance.

The CHAIRMAN observed that the economy of the elevator in this case lay simply in its using steam that was not wanted for any other purpose, though the steam might of course be employed in a much more economical way in an engine, if fuel were of any importance.

Mr. C. W. SIEMENS said that although the injector was very beautiful and economical in action where water had to be raised and also to be heated, as in feeding a boiler, it was remarkably deficient in respect of economy when employed simply as an elevator for raising water, where the water was not required to be heated. This was shown in the experiment which had been mentioned, where the water was raised only 36 feet high in being heated 26° ; but the perfect equivalent of heat, as established definitely by Joule's investigations and others subsequent, was that the heat required to raise 1 lb. of water 1° in temperature would raise 1 lb. a height of 772 feet, and 1 lb. heated 26° would raise 1 lb. a height of 772 × 26 or 20072 feet; hence the economy of the elevator was as 36 to 20072, or only 1-560th of the theoretical perfect duty of the heat. A very good pumping engine realised 1-6th of the theoretical effect, and ordinary steam engines realised 1-10th to 1-14th and were consequently 40 to 56 times superior in duty to the elevator. The elevator was therefore economically applicable only where fuel was no object, or as an injector where the heat came in again usefully, as in feeding a steam boiler.

The injector indeed, although inferior to a pump in mere propelling power, he considered the most perfect instrument for feeding boilers, so long as the supply water was cool enough to allow it to work; for then all the heat imparted to the water was returned into the boiler without any waste, whereas in using steam to work a pump the larger part of the heat was wasted by being thrown away with the exhaust steam. The injector however would not be economical if the supply water could be heated by other means free of expense, since its action required the supply water to be kept cool.

The amount of condensation in the long steam pipe mentioned in the paper seemed small for such a length of pipe, and he thought a good deal of water must be carried across the depositing box by the current of steam and pass through into the elevator. He had seen lately in France a simple and efficient contrivance by M. Le Chatelier for

freeing the steam from water, by making the steam pipe from the boiler descend vertically into the depositing box, surrounded by a cylindrical and concentric casing, from the top of which the steam was taken off for the engine; the wet steam rushing into the depositing box in a vertical current carried forward all the water it contained down to the bottom of the box by the velocity imparted to it, while the steam itself turned sharp round the bottom of the steam pipe and ascended through the annular space, passing off dry, and the water was allowed to drain back into the boiler. This apparatus was applied to a boiler which previously consumed 8 lbs. of water per lb. of fuel, and the result was that the consumption was reduced afterwards to only 6 or 6½ lbs. of water real evaporation per lb. of fuel, while the engine went much faster in consequence of having drier steam. But where the steam simply shot across the top of the depositing vessel, as in the apparatus that had been described, he was satisfied that a considerable quantity of water must be lost by being carried across with it.

Mr. E. A. Cowper agreed in thinking that some water would fly across with the steam in the depositing box described in the paper, instead of being separated from the steam. But he thought the best plan would be to superheat the steam at the top of the shaft sufficiently to prevent any condensation taking place in its passage to the elevator: by this means steam might be conveyed to a great distance without loss. He had proposed some time ago to superheat the steam highly above ground at a colliery in the neighbourhood, where a winding engine was wanted in the pit 400 yards from the shaft, and where there was an objection to having the boiler down in the pit, the upcast shaft not being quite large enough for producing the draught for the boiler as well as ventilating the workings: eventually however both boiler and engine were put at the bottom.

The Secretary had seen the elevator at work and witnessed the experiments described in the paper, and could confirm the statements as to its satisfactory working. A uniform pressure of steam was kept up without difficulty; and the elevator started promptly to work in the pit on turning on the steam. The two pressure gauges used at the same time at the boiler and the elevator in the experiments

were afterwards tried both together on the boiler, to check the correspondence of their scales.

Mr. M. Smith asked to what height water could be raised by the elevator.

Mr. R. Cunliffe replied that the height depended on the pressure of steam employed, and the adjustment of the steam and water orifices in the instrument. In the experiments at their works the tank into which the water was raised was only 36 feet above the elevator, and they had not yet had occasion to use the elevator for a greater height. The injector however worked up to 150 lbs. pressure per square inch in locomotive boilers, which was equivalent to 300 feet head of water.

Mr. C. W. Siemens thought there must be some imperfection in adjustment of the steam nozzle in the elevator at the colliery, not to get more than 1 foot lift for each lb. of steam pressure.

Mr. Wardle said the elevator was made without any means of adjustment, since economy in first cost of apparatus was the main object to be attained; and the elevator was therefore made of the cheapest possible construction, with the steam and water orifices permanently adjusted to the required sizes for the particular work to be done, but with an excess of steam supply, in order to enable the elevator to keep the pit always clear, even if a larger quantity of drainage water should be met with in the course of the workings.

Mr. E. A. Cowper observed that the proportion of 1 lb. of steam pressure per foot of height was evidently the result of the particular adjustment adopted in the elevator at the colliery; but as the injector would force water into its own boiler, and even into a boiler at a higher pressure than that from which the steam was supplied, the elevator was fully capable in ordinary work of raising the water 2 feet high or more for every lb. of steam pressure, by making the adjustment accordingly.

Mr. H. Woods thought that the elevator would probably be of much service in raising water where large quantities of hot water were wanted, as in breweries. He asked what was the lowest level from which the feed water could be drawn by it.

Mr. R. Cunliffe replied that 5 feet was the lowest level of the feed in their experiments with the injector, but this was dependent on the

quantity of steam used and the temperature of the supply water, for if the water were warm the injector would not draw it from so great a depth.

Mr. J. TOMLINSON had found the injector would work when the supply water had to be lifted 5 feet by suction, but stopped if that depth was exceeded even by only an inch or two.

Mr. M. SMITH thought in many cases the elevator might be wanted alternately for the two purposes of raising water for filling a tank as an elevator, and also feeding a boiler as an injector: and with suitable means of adjustment and disconnecting there seemed no reason why the same instrument should not be employed in the double capacity.

The CHAIRMAN remarked that the application of the injector as an elevator to the drainage of mines opened a very large field for its use; and for supplying blast furnace tuyeres with water it would also be of much value in the iron-making districts. A large quantity of steam was at present wasted under a variety of circumstances, which might be turned to use advantageously by the elevator, without entailing the serious outlay required for pumping machinery.

He proposed a vote of thanks to Mr. Wardle for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF SELLERS' SCREWING MACHINE.

By Mr. CHARLES P. STEWART, of Manchester.

The Screwing Machine described in the present paper was designed by Mr. W. Sellers, of Philadelphia, United States, to combine accuracy of cut and greater perfection of thread than is obtained in ordinary screwing machines, with rapidity of action and simplicity of working and with increased facility for keeping the cutting dies in good order. The screw thread is cut in a single operation, and the finished bolt is released by the withdrawal of the dies, the machine being driven continuously in one direction, without reversing or stopping.

The machine is shown in Plates 55 to 57; Fig. 1, Plate 55, is a longitudinal section through all the working parts of the machine, and Fig. 2, Plate 56, an end elevation. Fig. 5, Plate 57, is a longitudinal section of the die box, enlarged to one third full size; and Fig. 6 is a front elevation of it, with the cover plate removed in order to show the dies.

The dies for cutting the screw thread are in three separate pieces AAA, Fig. 6, Plate 57; these are advanced and held in the required position for screwing the bolt by means of eccentric ribs or cams fixed upon the cover plate, as shown in section at BBB, which work in a notch in the edge of each die, as shown in Figs. 5 and 7. In working, the die box C revolves in the direction of the arrow, being driven from the driving shaft D, Fig. 1, by the pinion E and spur wheel F; and the projecting clutch G on the back of the wheel F carries round with it the cam plate H, which thus revolves at the same speed as the die box C, so that the relative position of the cams and dies remains unaltered in revolving, and the dies are held up to the proper position for cutting the thread without alteration during working.

When the screwing is completed, the bolt is released by the dies being all simultaneously withdrawn by means of the cams: this is effected by the second pinion J, Fig. 1, Plate 55, gearing into the spur wheel K fixed on the shaft of the cam plate H. This pinion J is a little larger in diameter than the driving pinion E, and runs loose on the driving shaft D during the time that the dies are in operation cutting a screw; but when that is completed, the conical friction clutch between the two pinions is caused to engage by pressing forward the handle L, shown dotted in Fig. 1, whereby the spur wheel K being of a little smaller diameter than the wheel F is made to revolve faster than the latter, and causes the cam plate H to over-run the die box C; the dies A, Fig. 6, are thus made relatively to move back along the cams, so that they are withdrawn from the finished bolt, which being released is drawn out by hand, while the machine is still driven continuously in the same direction without stopping or reversing. The handle L on being released is immediately brought back to its original position by means of the counterbalance weight attached to it, thereby disengaging the pinions E and J, and pressing the loose pinion J against a leather collar on the end frame of the machine, the friction of which checks the motion of the pinion J and the spur wheel K of the cam plate, allowing the die box C to overtake the cam plate again; the dies are thus moved forward along the cams till they are again in their original working position ready for cutting a fresh thread.

The adjustment of the dies to the exact position required for the size of bolt to be cut is accomplished by means of a graduated index M, Fig. 2, on the spur wheel F which drives the die box C. The wheel F is loose on the shaft of the die box, and in working is clamped by set screws to the arm N, Figs. 1 and 2, which is keyed on the shaft. For advancing the dies, the arm N is turned forward in the direction of the rotation, as shown by the arrow in Fig. 2, carrying the dies forward along the cams, the latter being held stationary at the time by holding the spur wheel K that is fixed on the cam plate shaft. The dies are thus advanced to the position for cutting, and the spur wheel F is then clamped securely to the arm N by the set screws, having previously been turned so that the projecting clutch G on the

back of the wheel F is engaged with the wheel K of the cam plate. The machine is then ready for starting to work. The total length of the graduated index corresponds with the total length of the cams; and two holes in the wheel F for each of the set screws are sufficient to admit of adjustment throughout the entire range of the index, by means of the slotted arc at each extremity of the arm N.

For changing the dies in the die box, the spur wheel K is turned forward by hand as far as it will move; this brings the dies opposite the openings O in the cam plate H, Figs. 5 and 6, Plate 57. The three fixing screws P are then slacked back till their inner ends are flush with the inside of the cover plate, when the dies can be pushed out through the holes O. In putting in the fresh dies, each die is inserted in turn and pushed down until the notch in its edge comes opposite the fixing screw P, which is known by a shoulder on the screw driver; and the cam plate is worked backward and forward by hand, by means of the wheel K, to make sure of the die being properly placed with the notch fitting on the cam; the fixing screw is then set up, which secures the die from falling out.

In order to cut a full screw thread on the bolt in once running up, the dies are cut with a perfectly full thread throughout, and of such size as to fit the bolt when it has the thread cut complete upon it. The tops of the die threads are then eased off on the side where the bolt enters, as shown at R in Fig. 7, Plate 57, commencing at the base of the thread and terminating at the top of the third or fourth thread from the point of entering. The thread on the bolt is thus formed by a succession of cuts, each one deeper than the preceding, until the full depth is attained.

When the machine is used for tapping nuts, the cutting dies are removed, and the tap holder, shown in Figs. 8 and 9, Plate 57, is inserted in the hollow spindle of the die box, and secured from turning by a blank die, Figs. 10 and 11, which serves as a key fitting into the notch in the tap holder.

The bolt or nut to be screwed is fixed in the sliding holder S, Figs. 1 and 3, Plates 55 and 56, sliding freely on the top edge of the framing; the handle T is made with a finger on it to fit in a rack on

the framing; which gives sufficient leverage for the momentary pressure that has to be put upon the bolt on its first contact with the cutting dies to ensure its entrance. The clamps U for gripping the bolt or nut, shown separate in Fig. 4, are opened or closed simultaneously, one up and the other down, by two right-and-left-handed screws geared together by the pinions V and worked by the hand wheel W. It is essential that the bolt or nut to be screwed should be truly in the axis of the die box, which is ensured by boring the clamps in their places in the machine, and they are afterwards slotted to the required shape.

In cutting new dies or re-cutting old ones, a set of master taps is used; the leading end of the master tap is supported in a circular thimble which slides inside the hollow spindle of the die box. The dies are then pressed close upon the master tap by means of the arm N on the spindle of the die box, Fig. 1, Plate 55, and the machine is run forward and backward; the dies are again closed upon the tap, and the process repeated until a full thread is obtained. A small stop is first inserted in the clutch G between the spur wheels F and K, so as to make them immoveable with respect to each other during the process of cutting the dies.

In this machine the necessity of setting up the dies by hand between successive cuts is obviated, as they are set up at the first by the graduated index of the cam plate to the exact diameter required for the finished bolt, and the screwing is completed in once running the bolt up. With each machine a table is prepared showing the position on the index to which the pointer has to be set for cutting bolts of the various diameters within its range; and a slight change in the position of the pointer will make the bolts slightly larger or smaller, as the case may require. When the dies have become worn and have been re-cut, a readjustment of the index readily gives the means of bringing them up to exactly the same diameter as previously, so that the size of bolt is not altered by re-cutting the dies. The original adjustment of the index is made by actual trial of the different diameters of bolts in the machine, the results being tabulated; and this is done again when the dies are re-cut.

This screwing machine has the advantage of rapidity of action, producing a perfect screw thread in once running up, while the time usually required for running back is saved by the plan of withdrawing the dies and releasing the bolt. The machine is never required to be stopped except for changing or repairing the cutting dies, and does not need the application of a crossed belt or reversing apparatus for driving it, since it runs continuously in one direction only. It is of small size in proportion to the work it accomplishes, and is on a plan very convenient for the workman using it. As the dies can be readily adjusted to any diameter of bolt for which the machine is adapted, they can be worn down for a long time before requiring renewal.

Mr. CUNLIFFE exhibited one of the screwing machines in working order, and showed its action; also specimens of bolts screwed by the machine, and of the dies used.

The CHAIRMAN thought there were many points of interest in the machine, and had not previously seen one in which the entire screwing was done at a single operation without the machine being ever reversed. He enquired how many of the machines were in use and how long they had been at work, and what was the largest size of bolt that had been screwed by them.

Mr. CUNLIFFE replied that there were a good many of the machines in use in this country besides a considerable number in America, and they had had one at work for three years already at their works. The machine now exhibited was the smallest size made, for screwing bolts up to 1 inch diameter, and the largest sized machine screwed up to 2 inches diameter, as shown by the specimen bolt exhibited of that size: there was also an intermediate size of machine for screwing up to 1½ inch diameter. He showed a set of three dies which had been in constant use for six months and had

screwed 14,400 bolts of $\frac{7}{8}$ inch diameter, without ever being re-cut by the master tap; they had been faced only twice on the grindstone during the time, like an ordinary chasing tool of a screw-cutting lathe.

Mr. J. Murphy asked what was the cost of the machine, and whether it would cut a square thread as well as an angular one.

Mr. Cunliffe replied that the cost of the machine now shown for screwing bolts up to 1 inch diameter was about £68. They had not yet tried cutting any but an angular thread, but he expected the machine would do as well for a square thread if it were not too large for a single cut. The machine had a great advantage in rapidity of work by completing the screw at one cut: in the ordinary screwing machines the screw had to be run up three times to make a good thread, which with three times of withdrawing made six times altogether for the screw to pass through the machine, instead of once only in the new machine; in addition the time of stopping and reversing the ordinary machines was entirely saved in the new one, the machine running constantly in the same direction.

Mr. D. Joy enquired how many bolts would be screwed in a day by the machine, of $\frac{3}{4}$ inch diameter and screwed for a length of $1\frac{1}{4}$ inch. He had known 500 made per day of $10\frac{1}{2}$ hours, with a common screwing machine in which the dies were withdrawn for drawing back the bolt, when working as fast as possible. He asked also whether any difficulty was experienced from stripping the thread in cutting, when the cutting was completed by running once up the screw.

Mr. Cunliffe replied that he had never seen the thread stripped in any of the bolts, and the dies gave a clean cut like a chasing tool in a lathe, as shown by the specimens of bolts exhibited. The machine cut 92 screws per hour or about 960 per day of $10\frac{1}{2}$ hours in screwing $\frac{3}{4}$ inch bolts through $1\frac{3}{8}$ inch length.

Mr. D. Joy enquired whether the machine was run round by hand in re-cutting the dies by the master tap, in order to allow of working it backwards and forwards.

Mr. Cunliffe replied that a crossed strap was used at the time of cutting or re-cutting the dies, for the purpose of reversing the machine, but was required only on those occasions.

Mr. E. A. Cowper observed that there was a limit to the capability of cutting a thread by once running up in the machine, depending on the quality of iron that was being screwed: with a large thread the iron would give way and would not stand the extreme strain of cutting up the whole thread at once, unless it were of an unusually close and fine texture. He noticed that though the small bolts showed a good clean thread, the large bolt of 2 inches diameter had the thread ragged in several places. Probably in practice the large bolts would be run up two or three times to make a good thread. Bell-mouthed dies as used in the machine prevented the thread from being run up of the full depth right to the head of the bolt, but this was perhaps of little consequence in the general make of bolts.

Mr. J. Tomlinson thought that the new machine had the objections of the old ones with solid dies, and was much more complicated in construction, the only advantages being that the separate dies could be readily sharpened up, and the fact that the bolt could be released without running the machine back; but he thought it questionable whether even these advantages would compensate for the increased cost of the machine itself, and it appeared to him not equal to machines now in use in which bolts varying slightly in diameter could readily be cut. The differential motion of the cam plate and die box was certainly an ingenious contrivance.

Mr. J. Murphy asked whether different diameters of bolts could be screwed with the same dies.

Mr. Cunliffe replied that this might be done to some extent, but it would be at a sacrifice of the quality of the thread cut, owing to the cutting threads on the dies being in that case at a slightly different angle to the thread on the bolt they were cutting. To ensure a full and true thread, bolts should be cut only with dies made specially to suit their diameters.

The sliding holder was required to hold the bolt perfectly true in the centre line of the dies in order to ensure accuracy of work, and this was accomplished by making the machine bore its own hole in the holding clamps while in their places, and they were afterwards slotted out square, with witnesses of the boring left in to ensure strict accuracy.

The Chairman moved a vote of thanks to Mr. Stewart for the paper and the numerous specimens exhibited, and also to Mr. Cunliffe, which was passed.

The Meeting then terminated.

WROUGHT IRON LIGHTHOUSE. *Plate 3.*

Fixing of main Pillars on Piles.

Fig. 8. *Plan.*

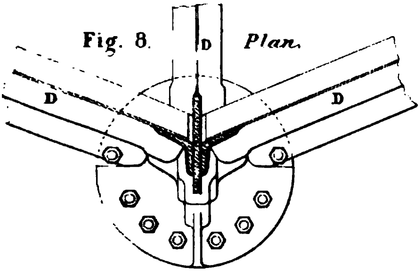


Fig. 10. *Plan of Pile Cap.*

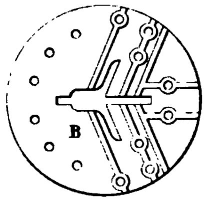


Fig. 9. *Elevation.*

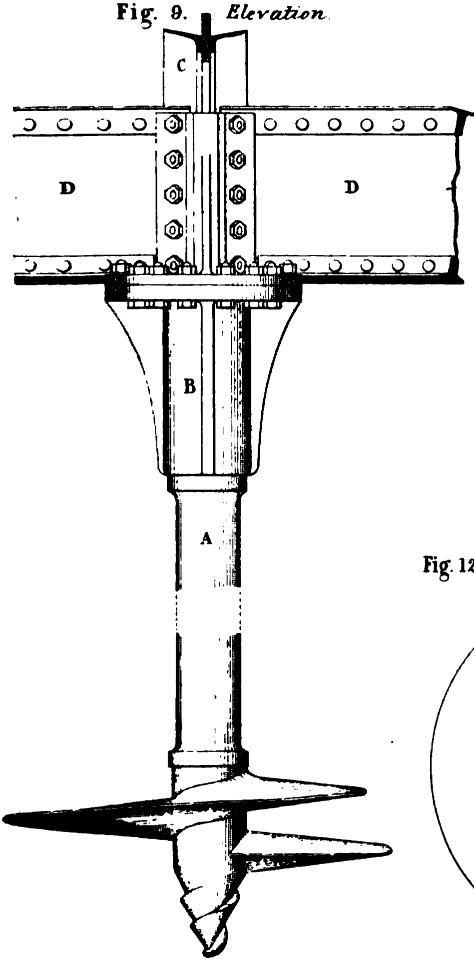


Fig. 11. *Vertical Section.*

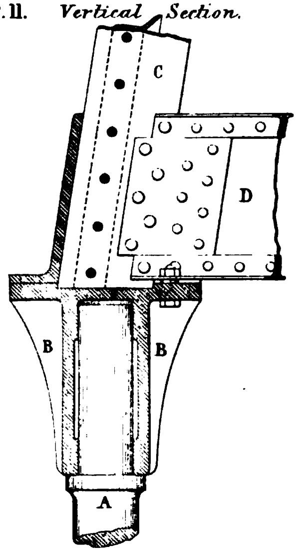
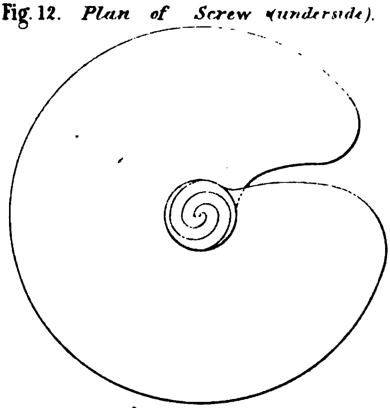


Fig. 12. *Plan of Screw (underside).*



Scale 1/24th. 10 5 0 10 20 30 40 50 *Inches.*

(Proceedings Inst. M.E. 1861. Page 15.)

WROUGHT IRON LIGHTHOUSE.

Plate 4.

Cast Iron Centre Column below house platform.

Section at XX.

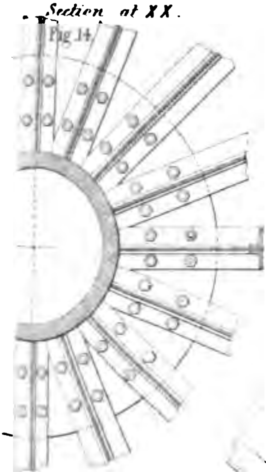
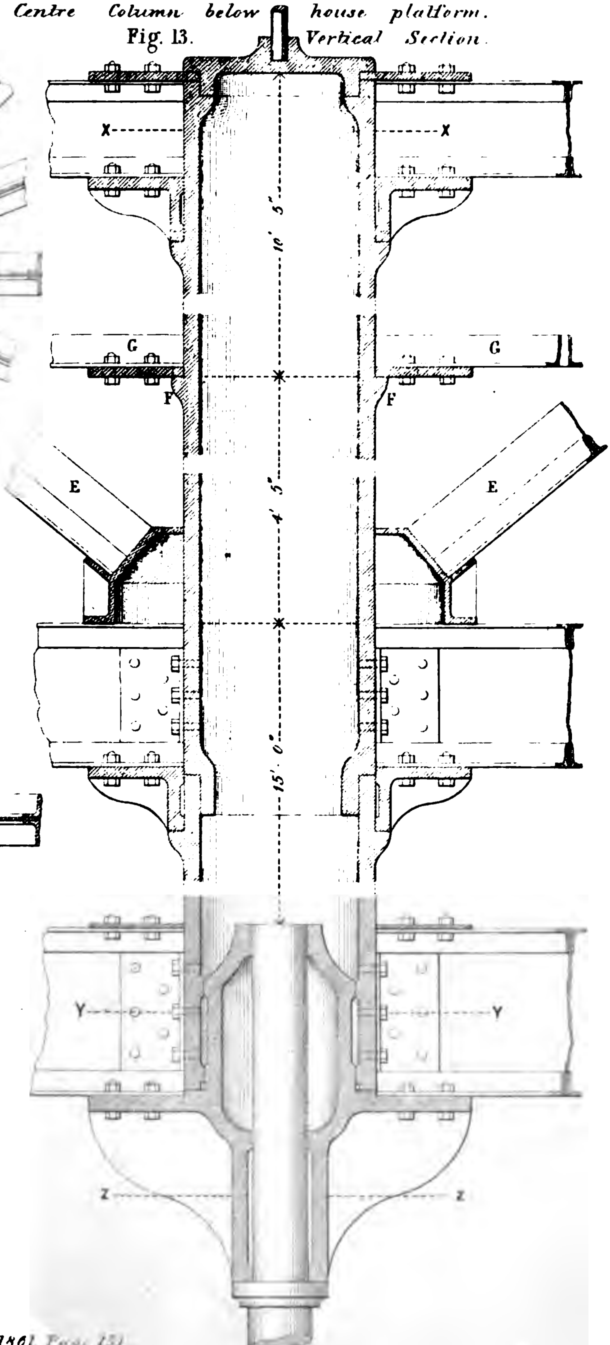


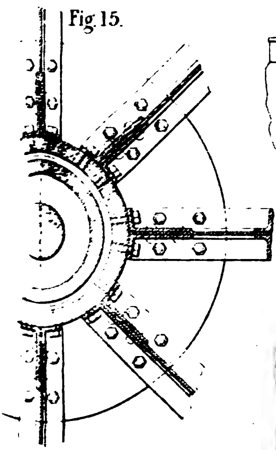
Fig. 14.

Fig. 13. *Vertical Section.*



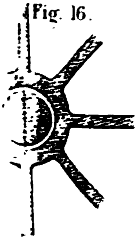
Section at YY.

Fig. 15.



Section at ZZ.

Fig. 16.



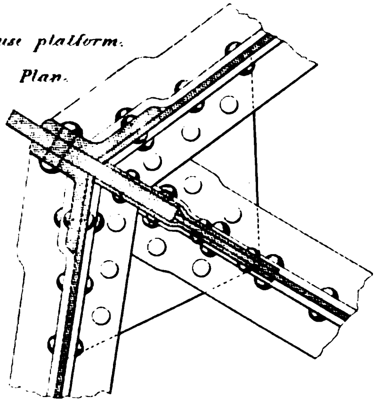
Scale 1/24th. 10 5 0 10 20 30 40 50 *Inches.*

WROUGHT IRON LIGHTHOUSE.

Attachment of horizontal Girders to Corner Pillars

Below house platform.

Fig. 17. Plan.



Above house platform.

Fig. 19. Plan.

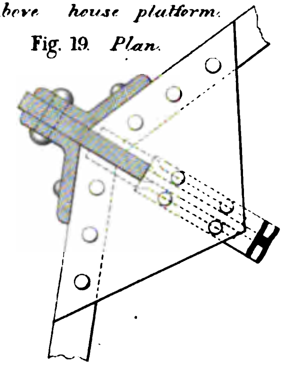


Fig. 18. Elevation.

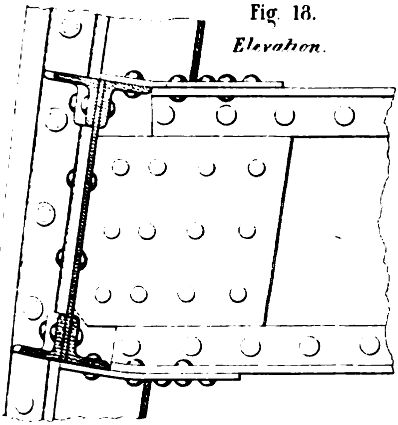
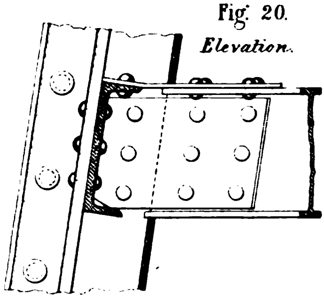
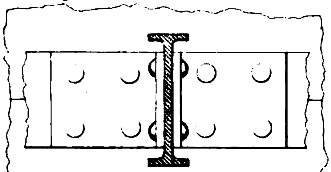


Fig. 20. Elevation.



Attachment of horizontal Girders to staircase Tower, (above house platform.)

Fig. 23. Elevation.



Attachment of horizontal Girders to cast iron Centre Column, (below house platform.)

Fig. 21. Elevation.

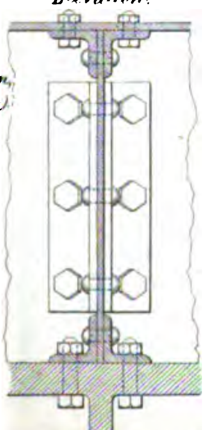


Fig. 22. Plan.

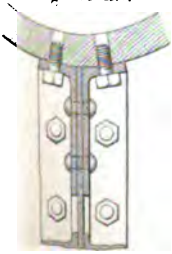
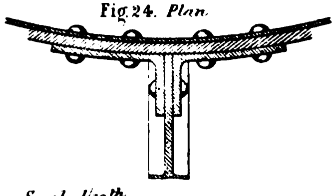


Fig. 24. Plan.

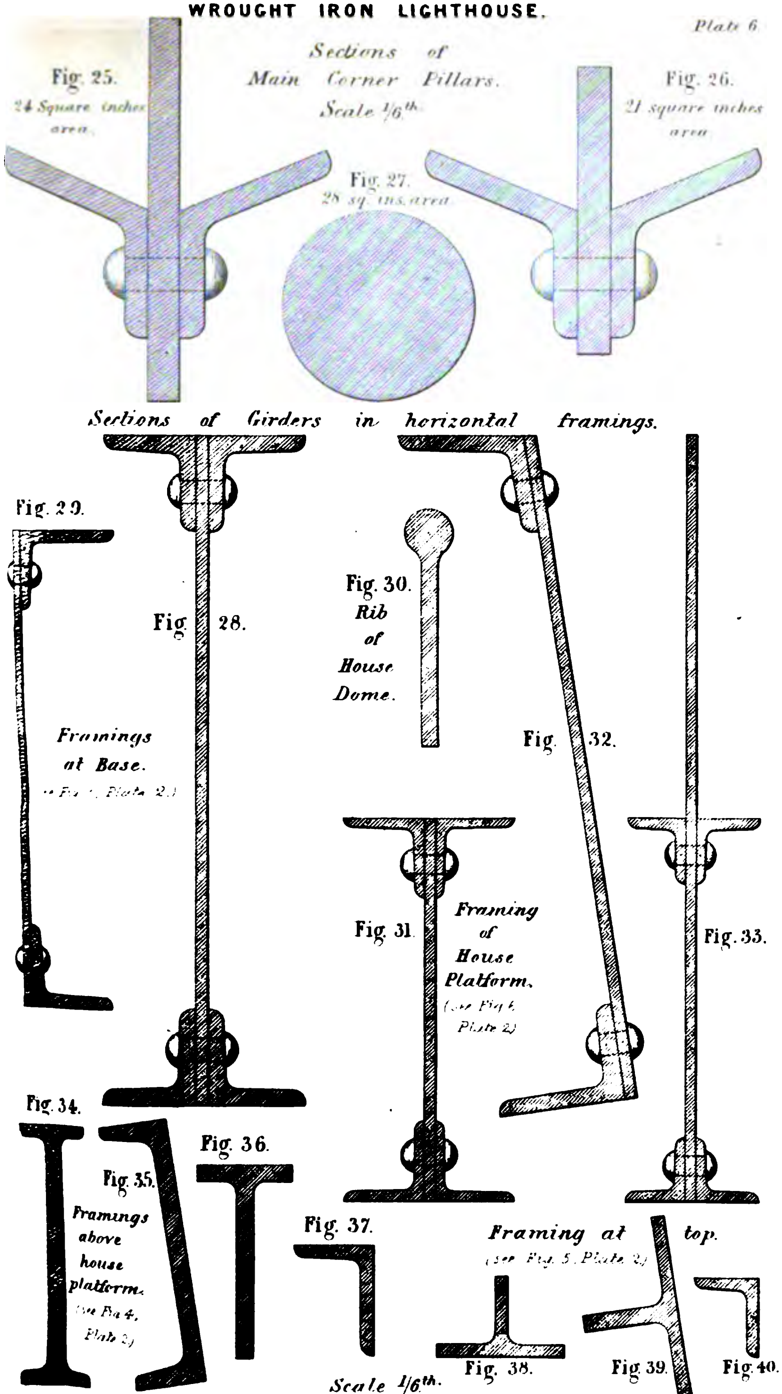


Scale 1/12th.

0 5 10 15 20 Inches

WROUGHT IRON LIGHTHOUSE.

Plate 6.

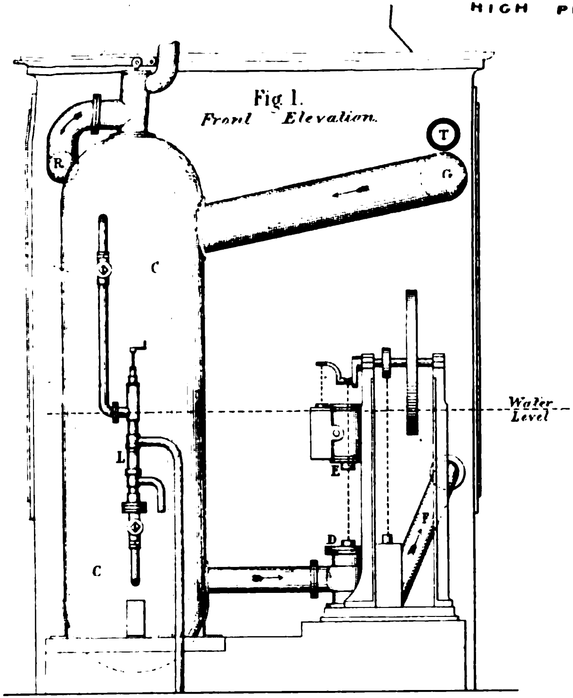


(Proceedings Inst. M.E. 1861. Page 15.)

Plate

HIGH PRESSURE STEAM BOILER.

Fig. 1. Front Elevation.



Scale 1/50th.

0 1 2 3 4 5 6 7 8 9 10 Feet

Fig. 2. Longitudinal Section.

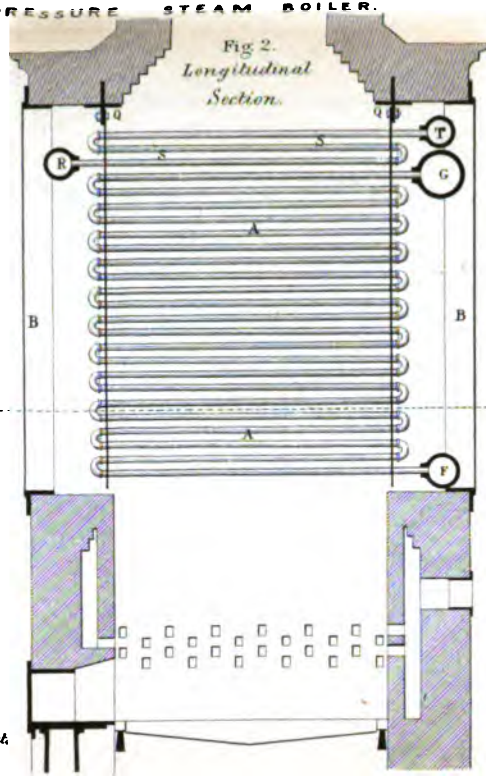
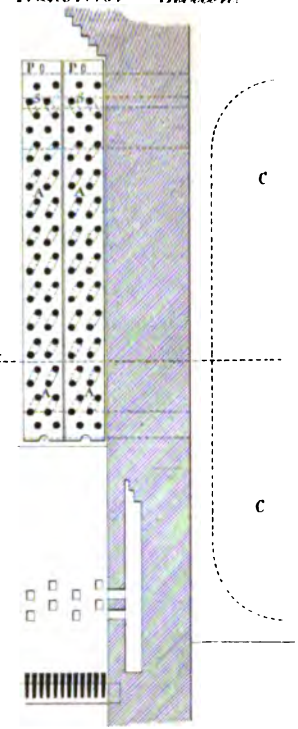


Fig. 3. Transverse Section.



(Proceedings Inst. M. E. 1861. Page 30.)

HIGH PRESSURE STEAM BOILER.

Plate 8.

Fixing of Tubes in boiler.

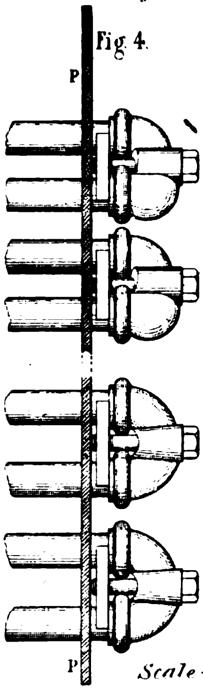


Fig. 4.

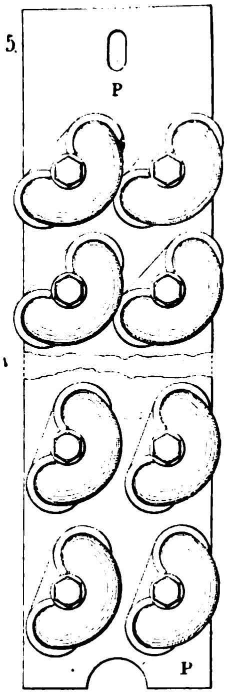


Fig. 5.

Scale 1/10th

Connexion of Tubes to main supply and delivery pipes

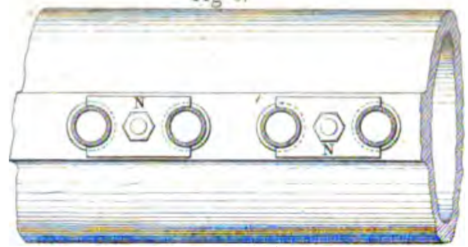


Fig. 6.

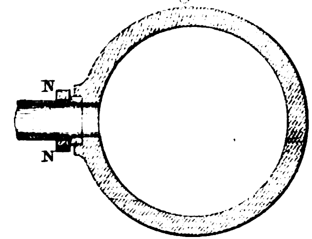


Fig. 7.

Scale 1/10th. 0 10 20 30 *Inches.*

Connexion of Tubes and Bends, enlarged.

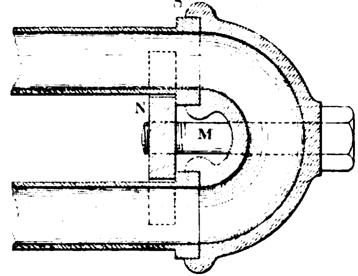


Fig. 8.

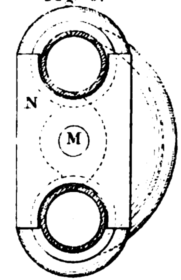


Fig. 9.

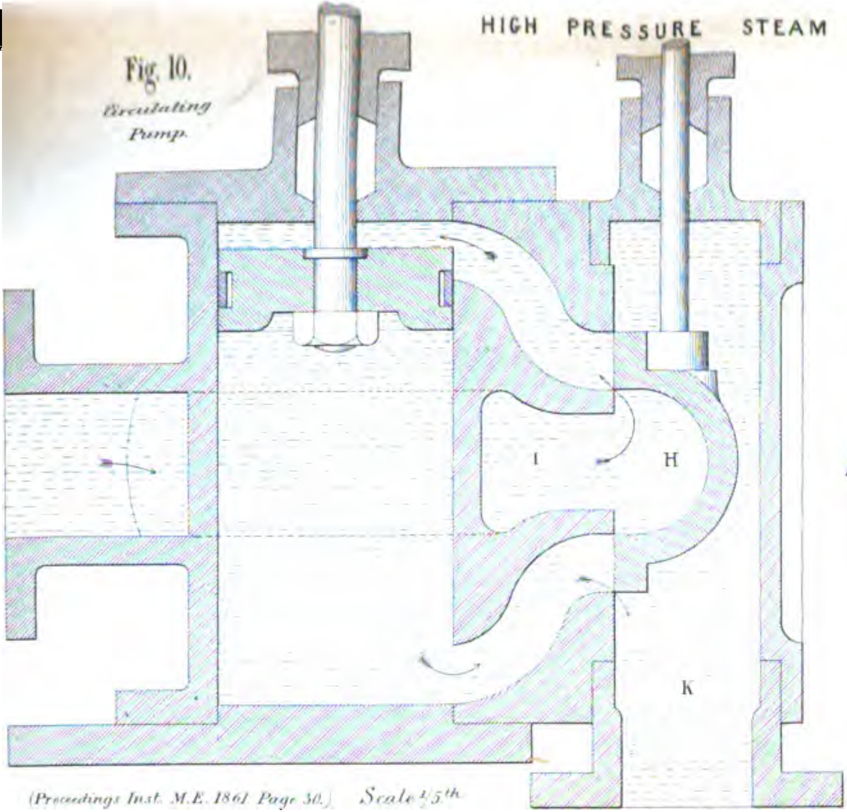
Scale 1/5th. 0 5 10 *Inches.*

(Proceedings Inst. M.E. 1861 Page 30.)

HIGH PRESSURE STEAM BOILER.

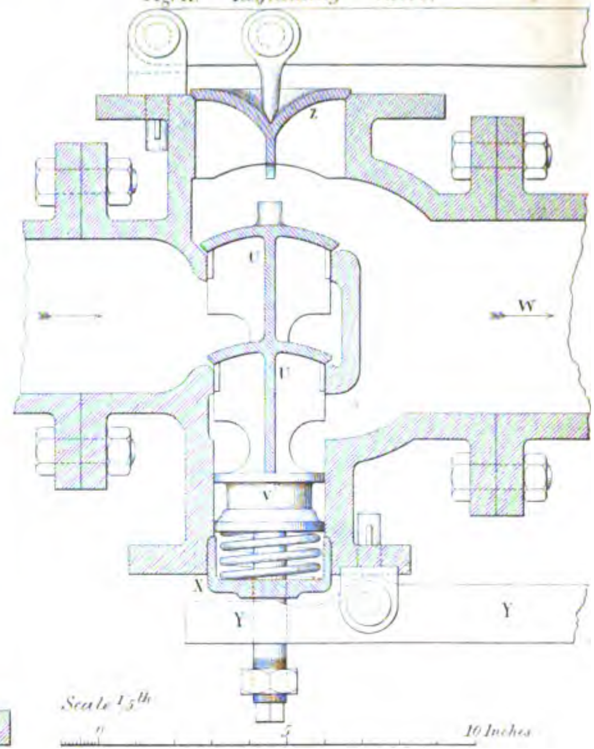
Plate 9.

Fig. 10. *Circulating Pump.*



(*Proceedings Inst. M.E. 1861 Page 30.*) *Scale 1/5th*

Fig. 11. *Regulating Valve.*



Scale 1/5th

LOCOMOTIVE WATER SUPPLY.

Plate 10

Fig 1 Longitudinal Section of Tender and Water Trough.

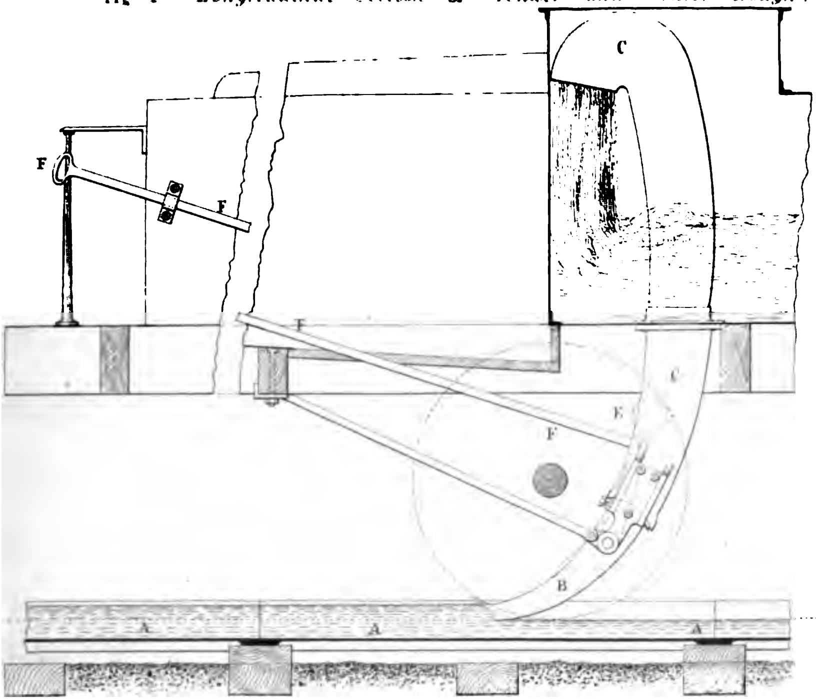
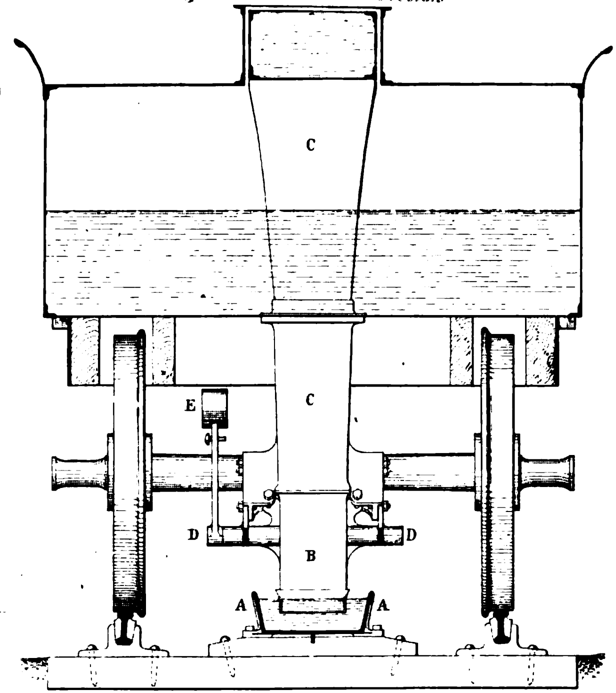


Fig. 2. Transverse Section.



(Proceedings Inst. M. E. 1861. Page 43) Scale 1/30th Ins 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

Plate II.

LOCOMOTIVE WATER SUPPLY.

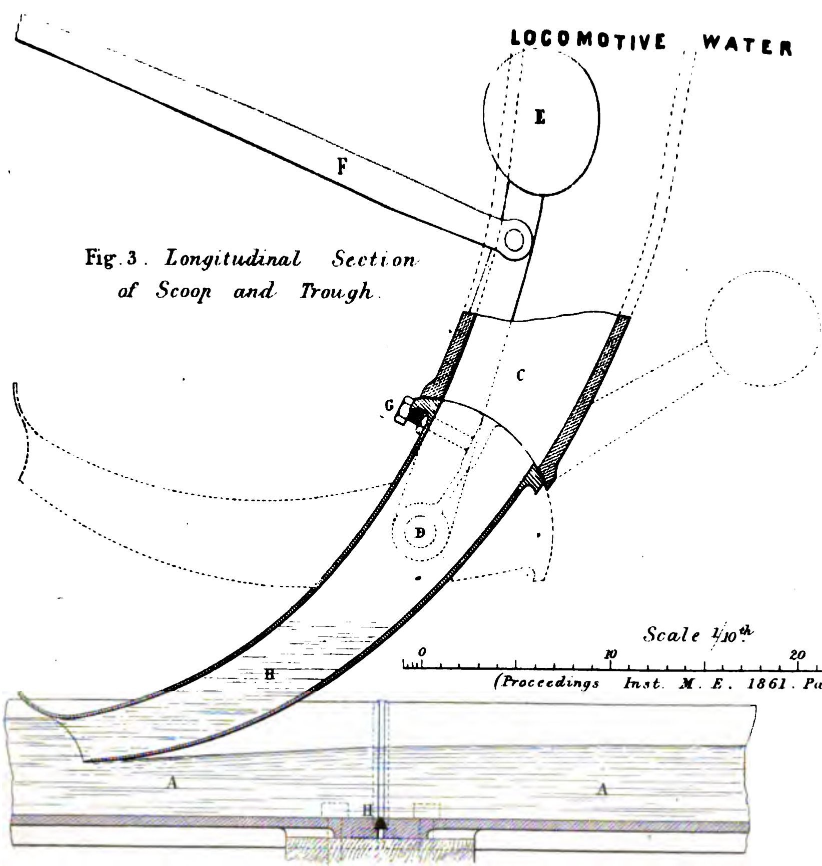


Fig. 3. Longitudinal Section of Scoop and Trough.

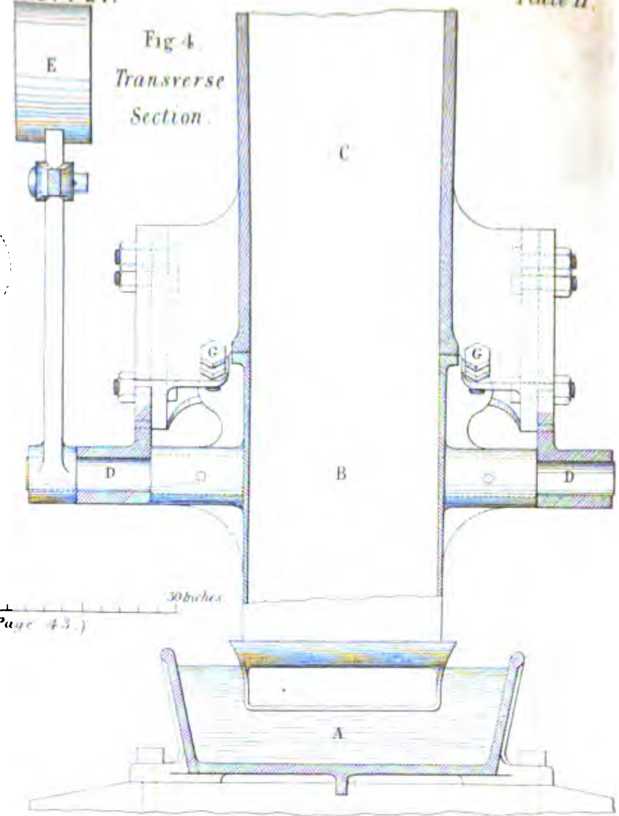


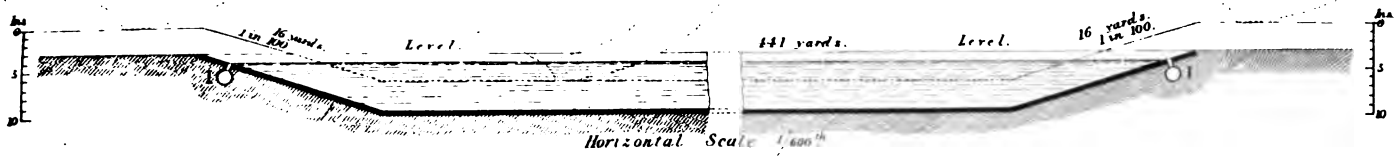
Fig. 4. Transverse Section.

(Proceedings Inst. M. E. 1861. Page 43.)

LOCOMOTIVE WATER SUPPLY.

Plate 12

Fig. 5 Diagram of Laying of Water Trough.



Ice Plough.

Fig. 7. Side Elevation.

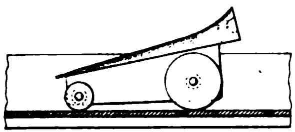


Fig. 8. Back Elevation.

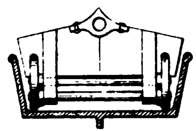


Fig. 9. Plan.

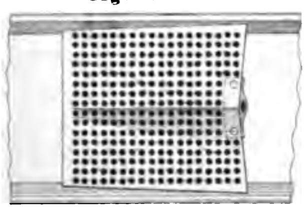
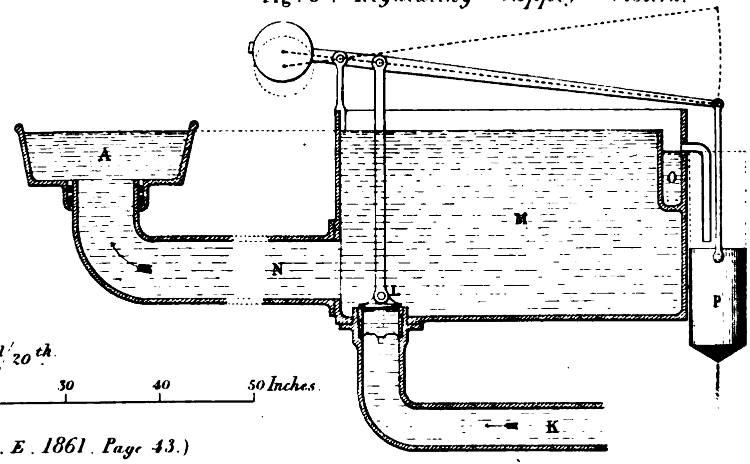
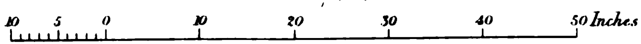


Fig. 6. Regulating Supply Cistern.



Scale 1/20th.



(Proceedings Inst. M. E. 1861. Page 43.)

LOCOMOTIVE WATER SUPPLY.

Velocimeter.

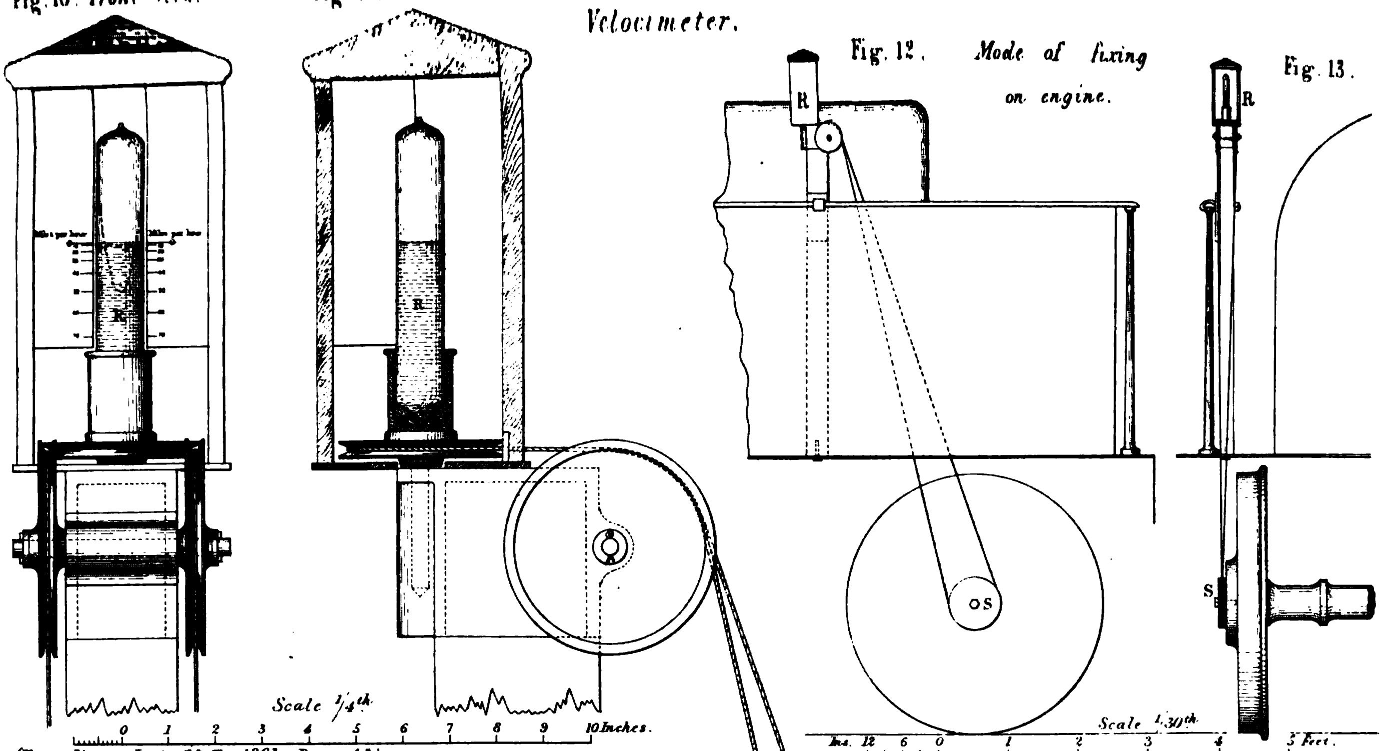


Fig. 10. Front View.

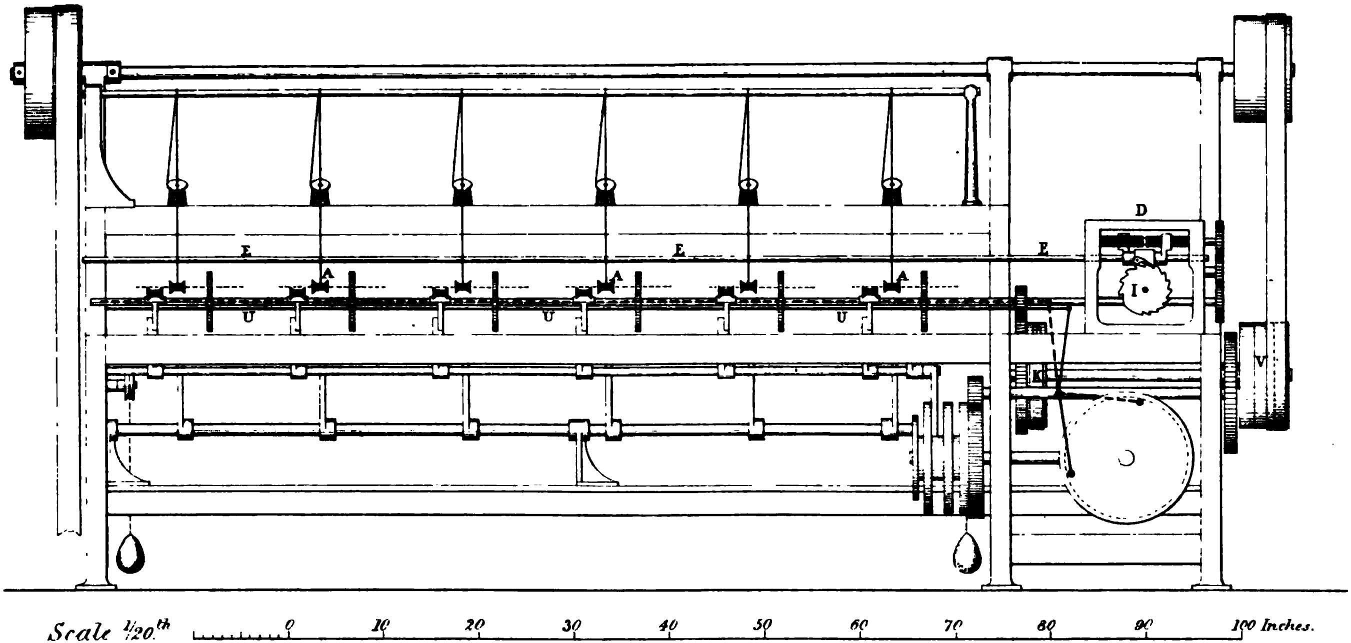
Fig. 11. Side View.

Fig. 12. Mode of fixing on engine.

Fig. 13.

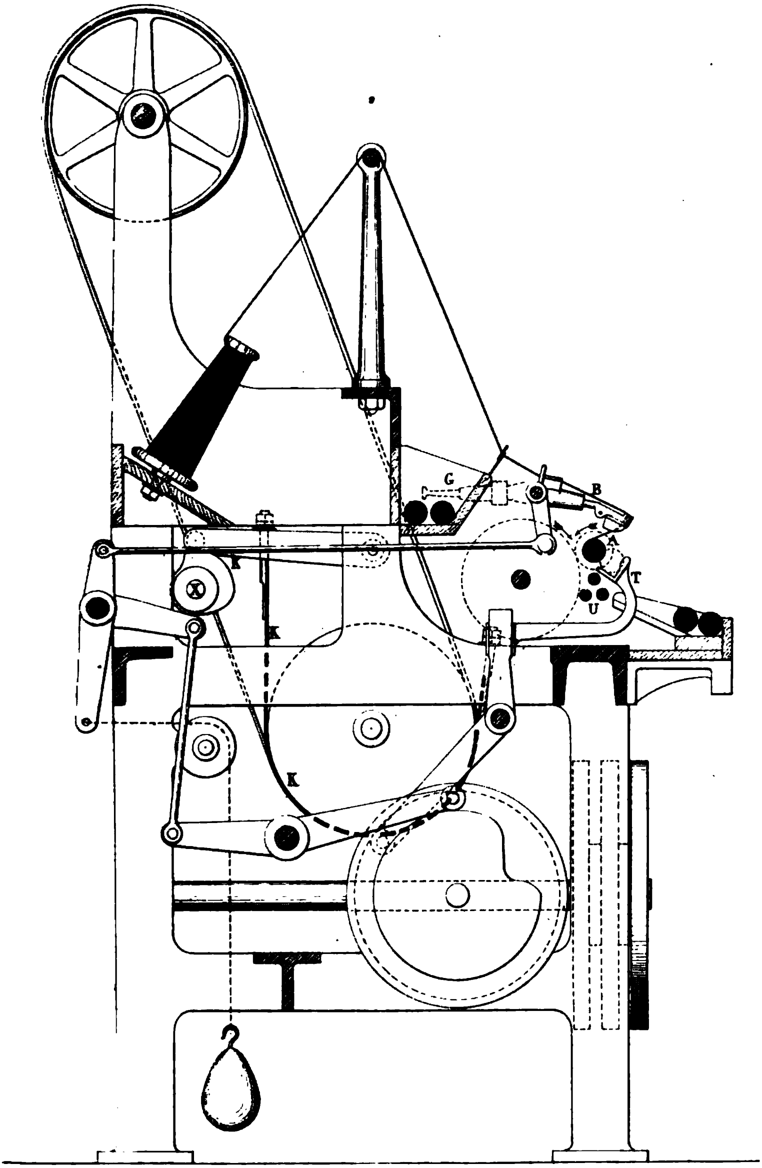
SPOOLING MACHINE.

Fig. 1. Front Elevation.



(Proceedings Inst. M.E. 1861. Page 54)

Fig. 2. *Transverse Section.*



Scale 1/10th 0 10 20 30 *Inches*

(Proceedings Inst. M.E. 1861. Page 54.)

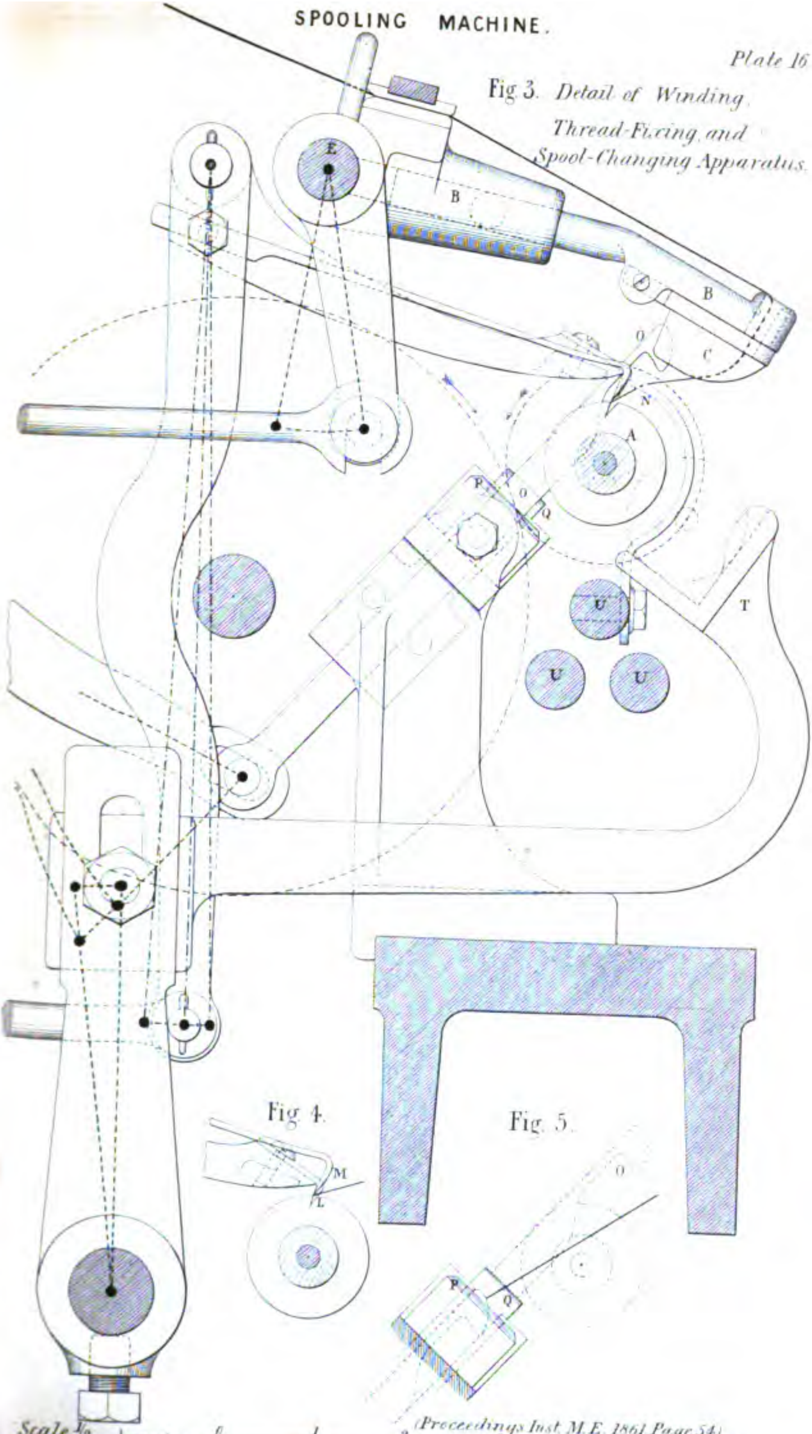


Fig 3. *Detail of Winding, Thread-Fixing, and Spool-Changing Apparatus.*

Fig 4.

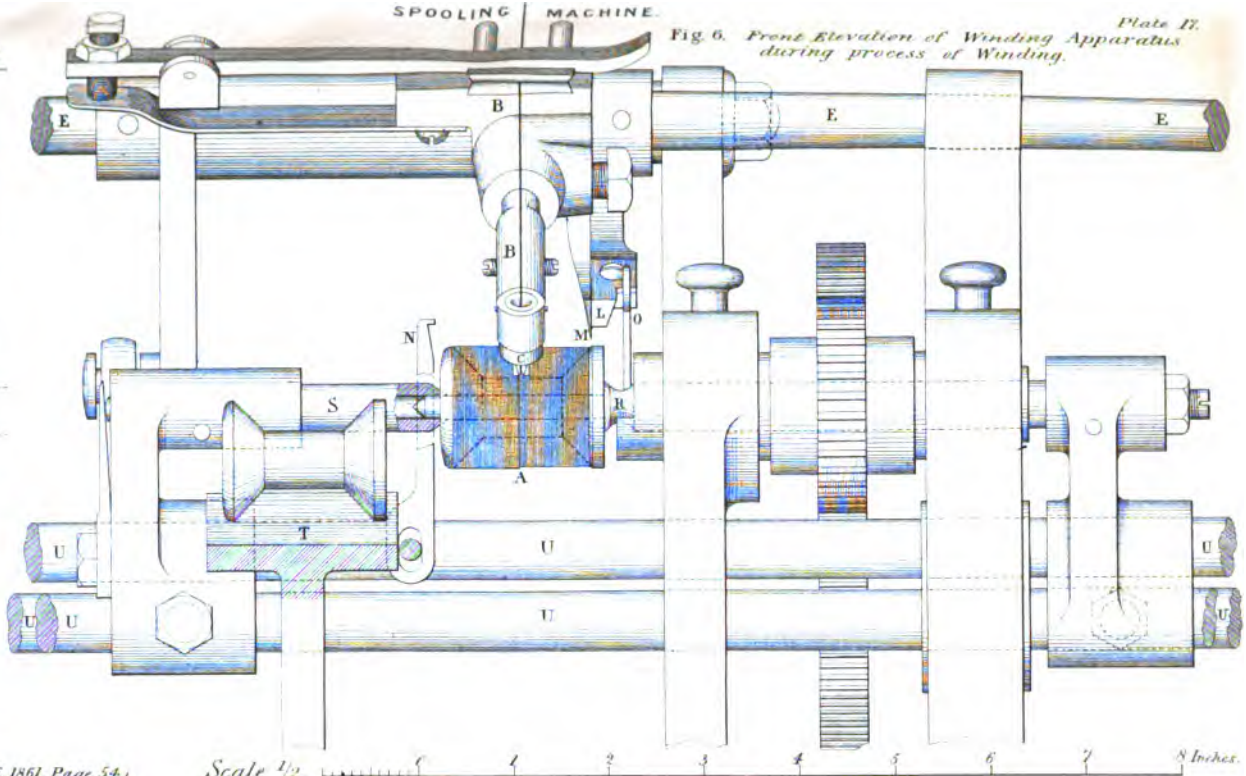
Fig. 5.

SPOOLING MACHINE.

Plate 17.

Fig. 7. Thread Fixing.

Fig. 6. Front Elevation of Winding Apparatus during process of Winding.



(Proceedings Inst. M.E. 1861 Page 54.)

SPOOLING MACHINE.

Plate 18.

Traverse Motion.

Fig. 8. *Transverse Section.*

Fig. 9. *Plan.*

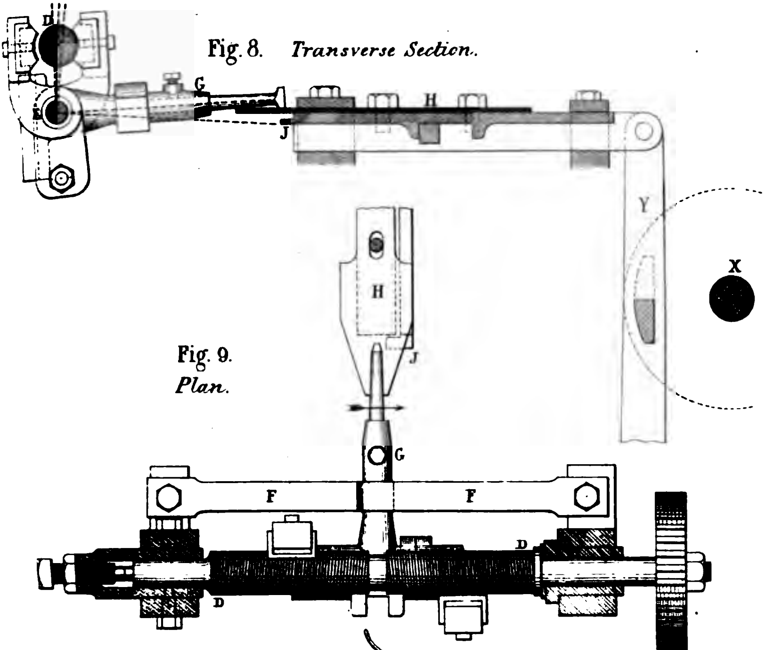


Fig. 10.

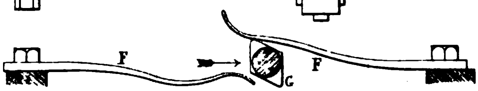


Fig. 11.

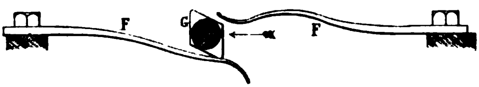
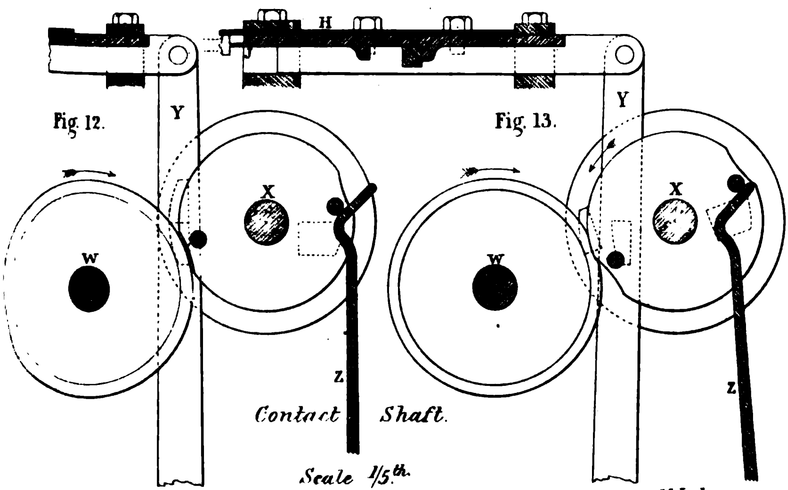


Fig. 12.

Fig. 13.



Contact Shaft.

Scale 1/5th.

0 5 10 15 *Inches.*

SPOOLING MACHINE.

Plate 19.

Diagrams of Cams performing Change Movements.

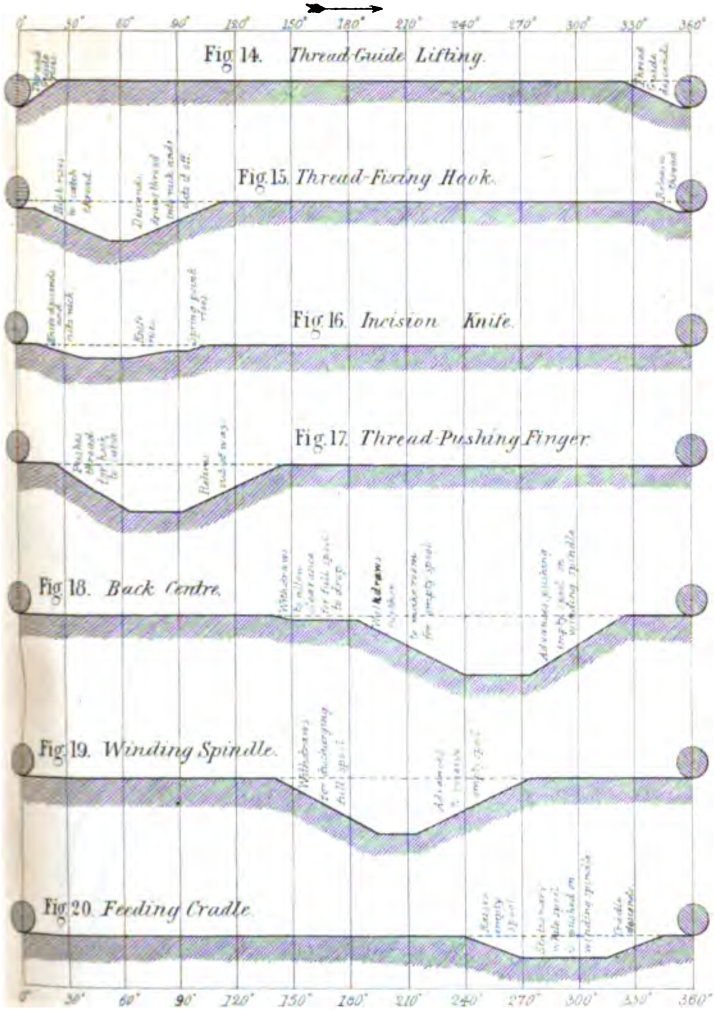
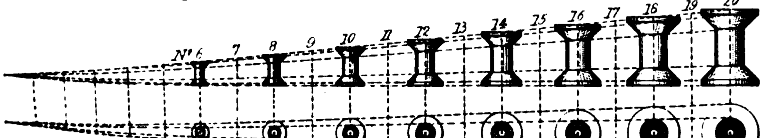


Fig. 21. *Scale of Sizes of Spools.*



Scale 1/5th. 0 1 2 3 4 Inches

Fig. 1. *General Elevation of Eaton's new Coke Ovens.*

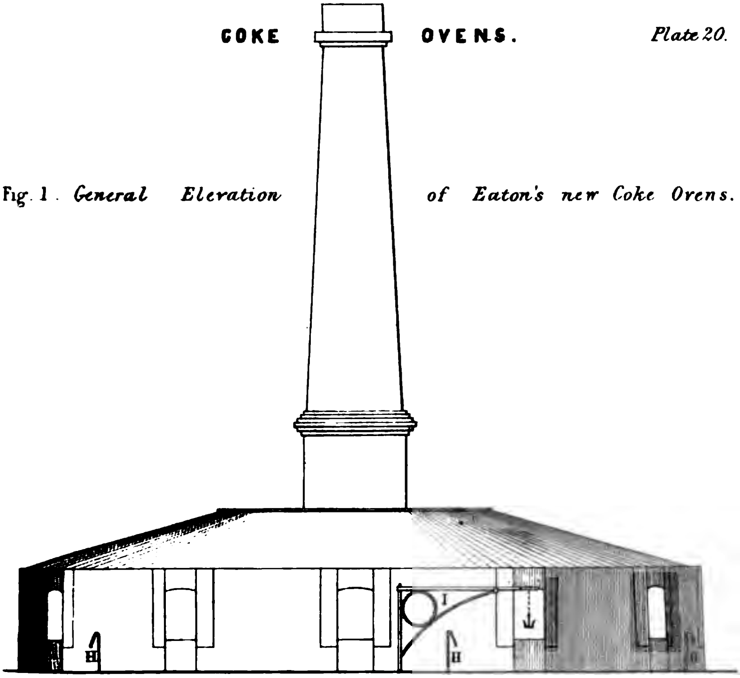
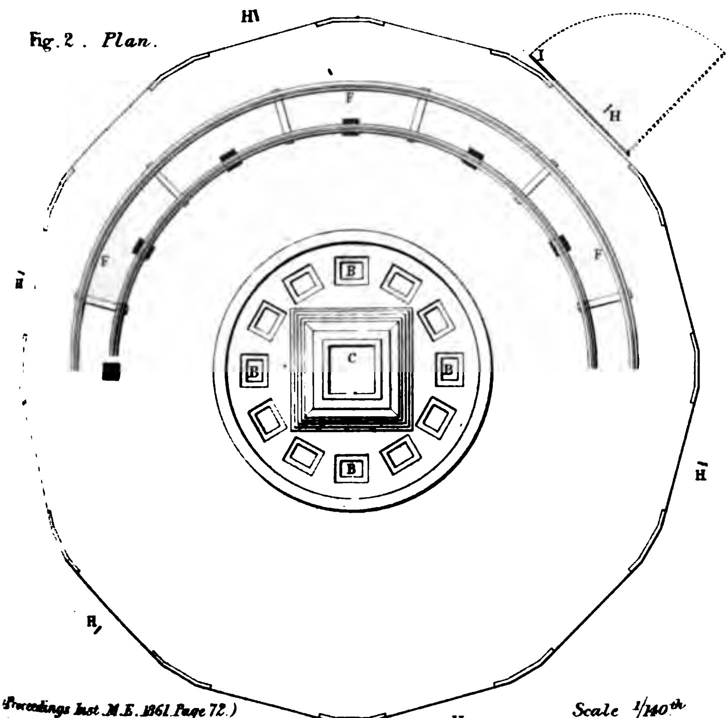


Fig. 2. *Plan.*



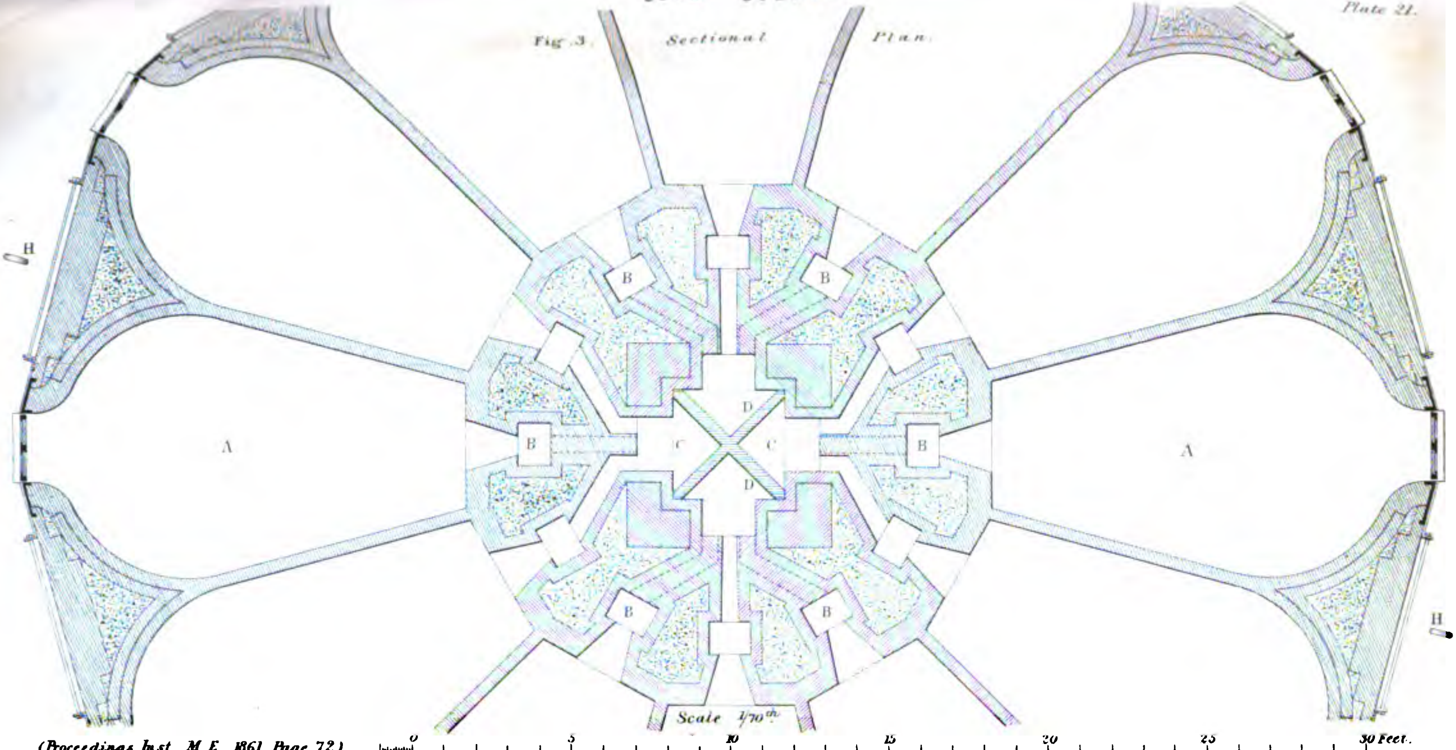
(Proceedings Inst M.E. 1861 Page 72.)

Scale 1/140th

0 5 10 15 20 25 30 35 40 45 Feet

COKE OVENS.

Fig. 3. Sectional Plan.



COKE OVENS.

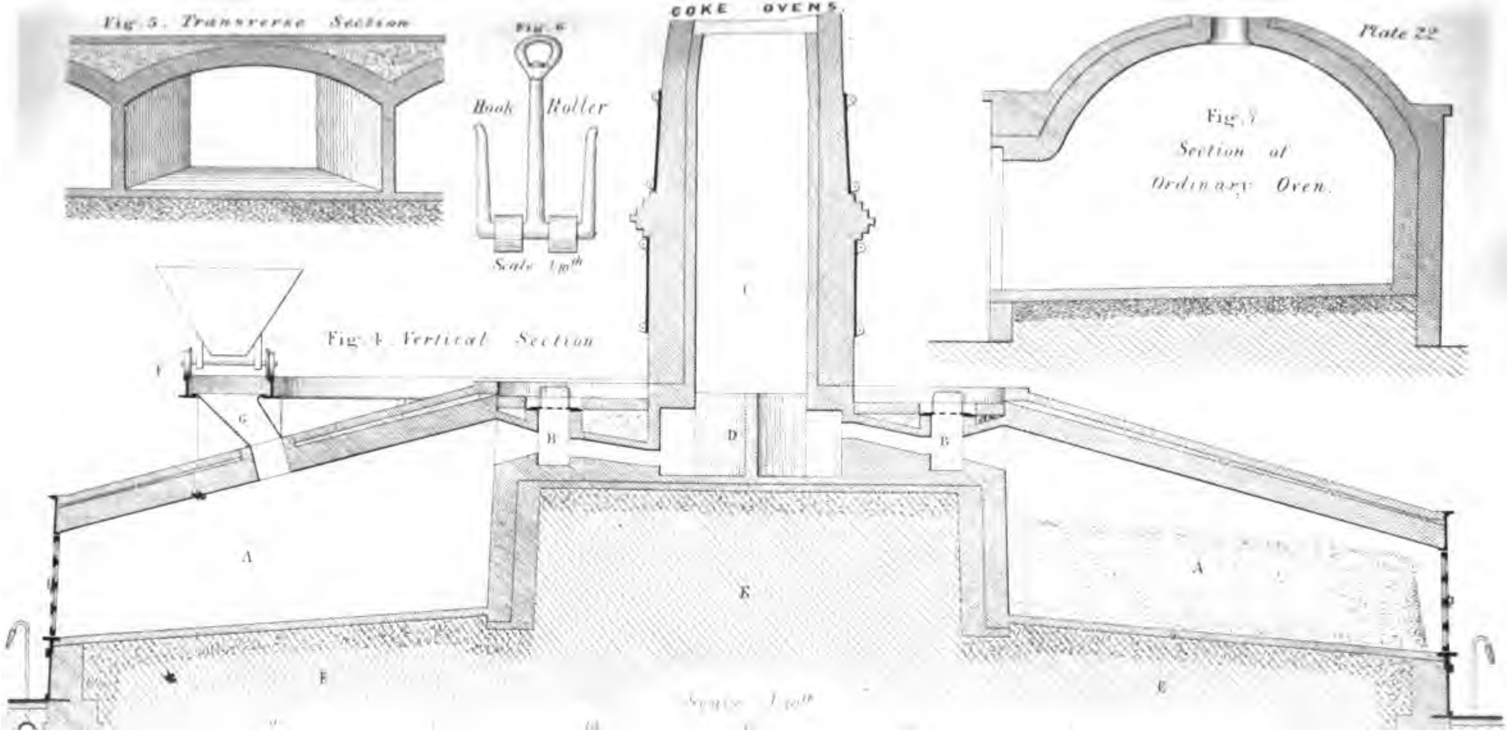
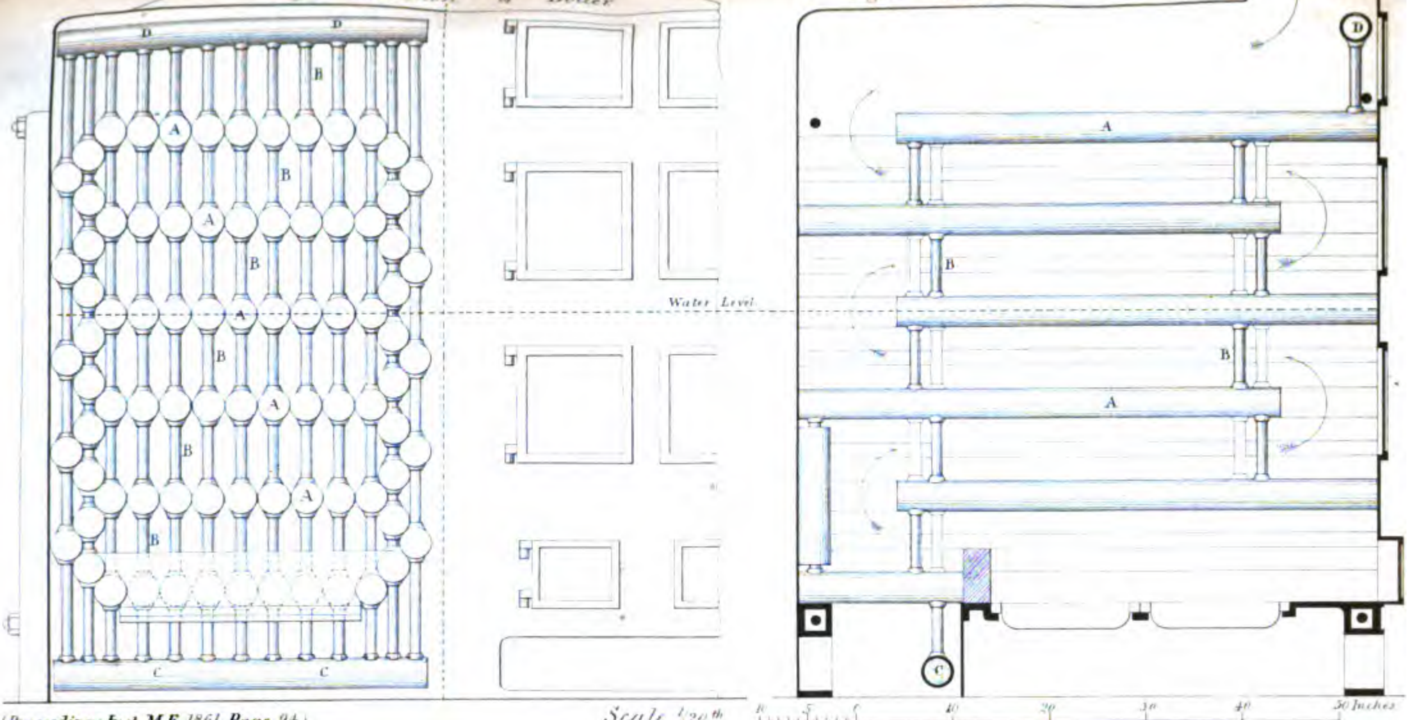


Fig. 5. Transverse Section
Fig. 6
Hook
Roller
Scale 1/10th
Fig. 4. Vertical Section
Fig. 7
Section of
Ordinary Oven.
A
B
C
D
E
G
A
B
E
E

HIGH PRESSURE STEAM ENGINE.

Fig 1. Elevation of Boiler — Fig 2. Longitudinal Section.



Scale 1/20th

HIGH PRESSURE STEAM ENGINE.

Fig. 1. Elevation of Boiler

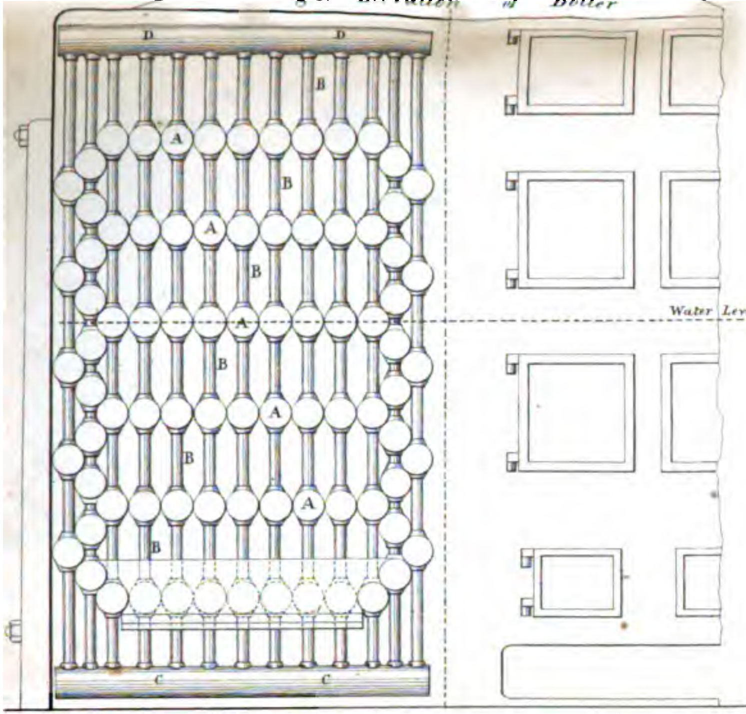
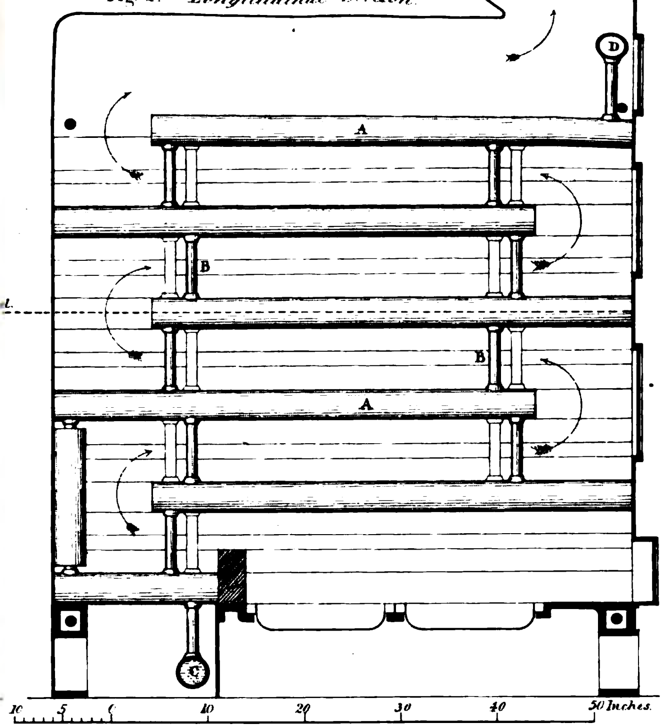


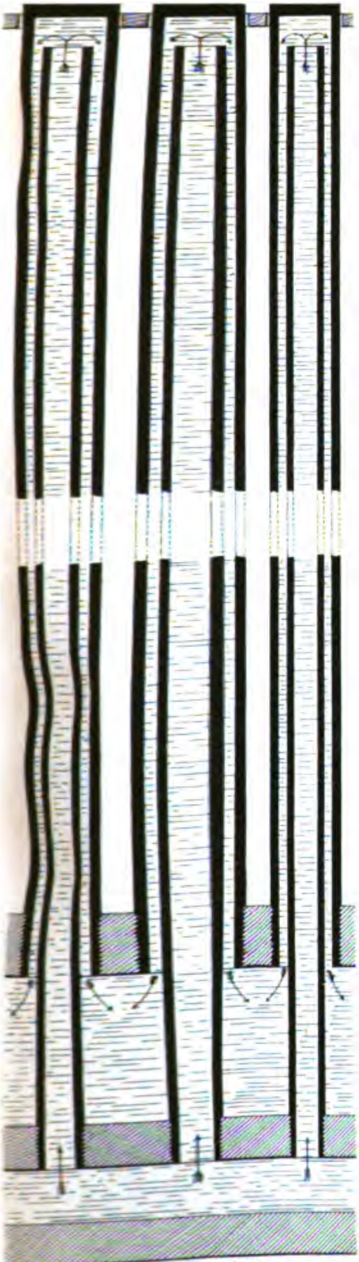
Fig. 2. Longitudinal Section.



Scale 1/20th

(Proceedings Inst. M.E. 1861. Page 94.)

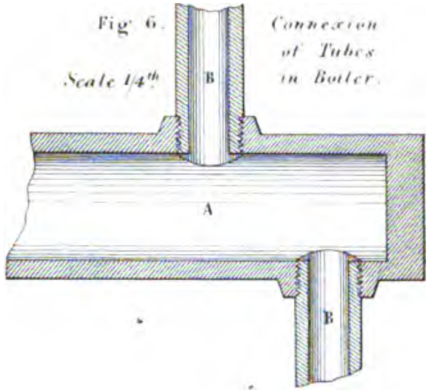
Fig. 5. Vertical Section of Surface Condenser.



Scale 1/4th.

Inches.

Fig. 6. Connexion of Tubes in Boiler. Scale 1/4th



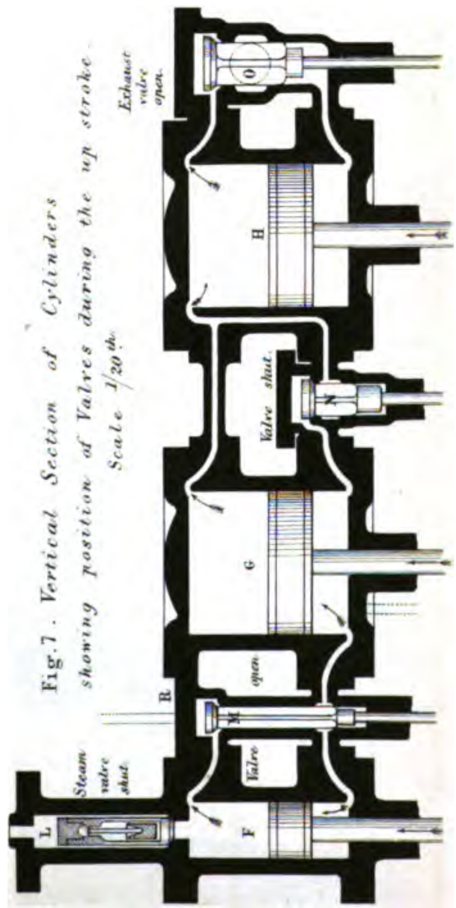


Fig. 7. Vertical Section of Cylinders showing position of Valves during the up stroke. Scale 1/20th.

Fig. 5. Vertical Section of Surface Condenser

Fig. 6.

Scale 1/4th

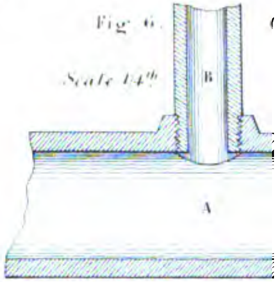


Fig. 7. Vertical Section of Cylinders showing position of Valves during the up stroke

Scale 1/20th

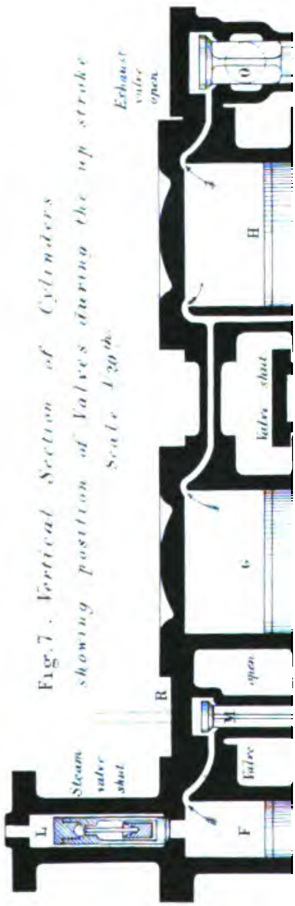


Fig. 8. Indicator Diagrams from 1st and 3rd cylinders

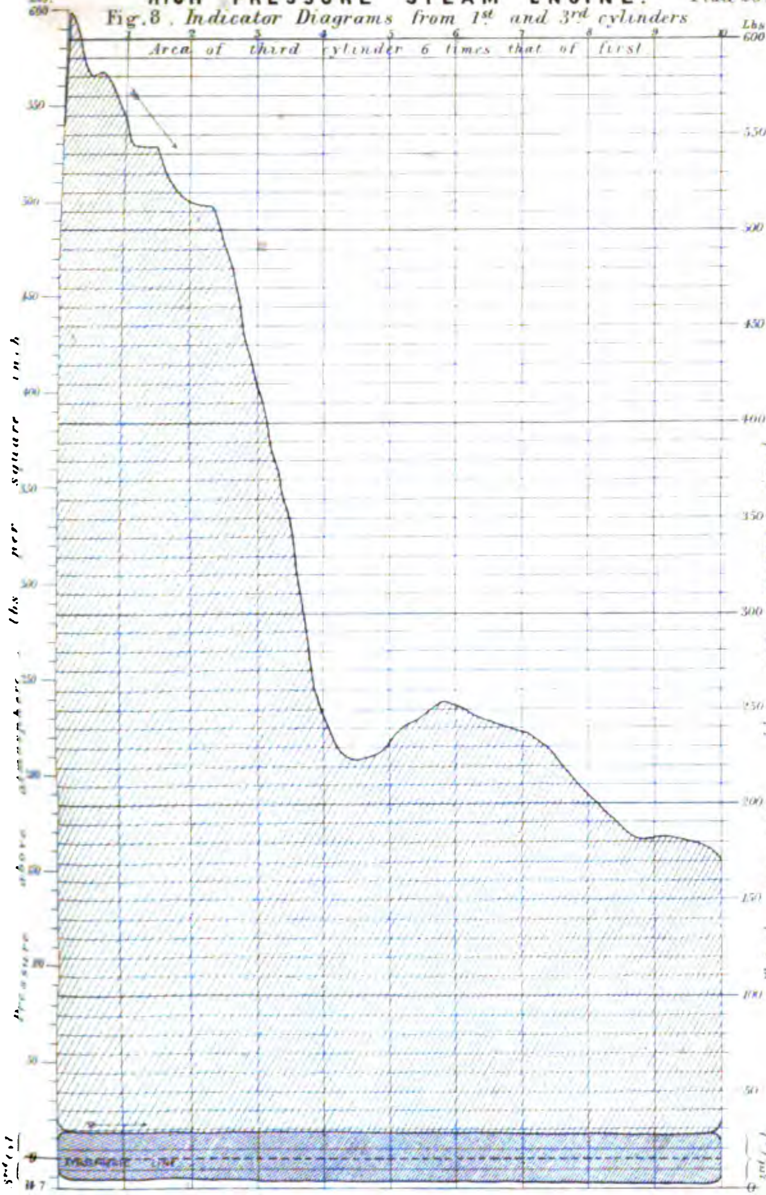
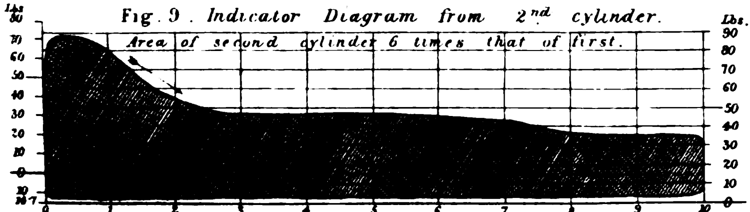


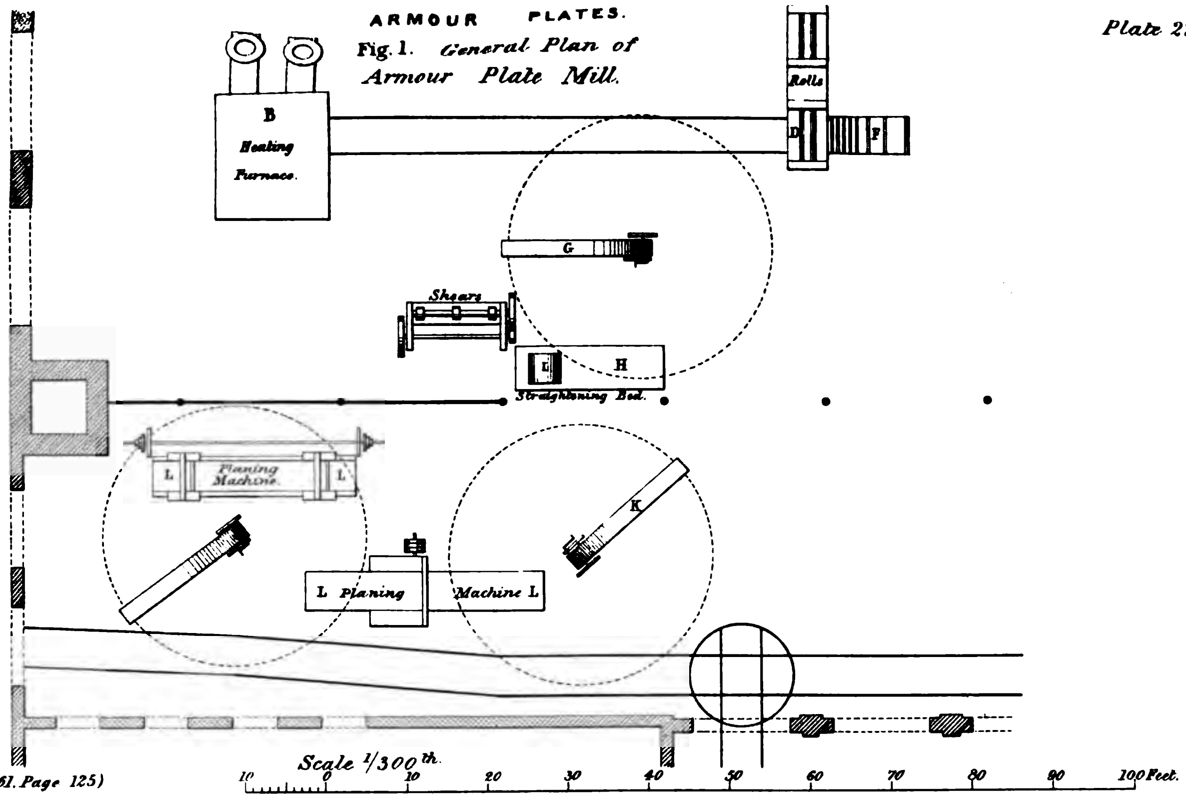
Fig. 9. Indicator Diagram from 2nd cylinder.



(Proceedings Inst. M.E. 1861. Page 94.)

ARMOUR PLATES.

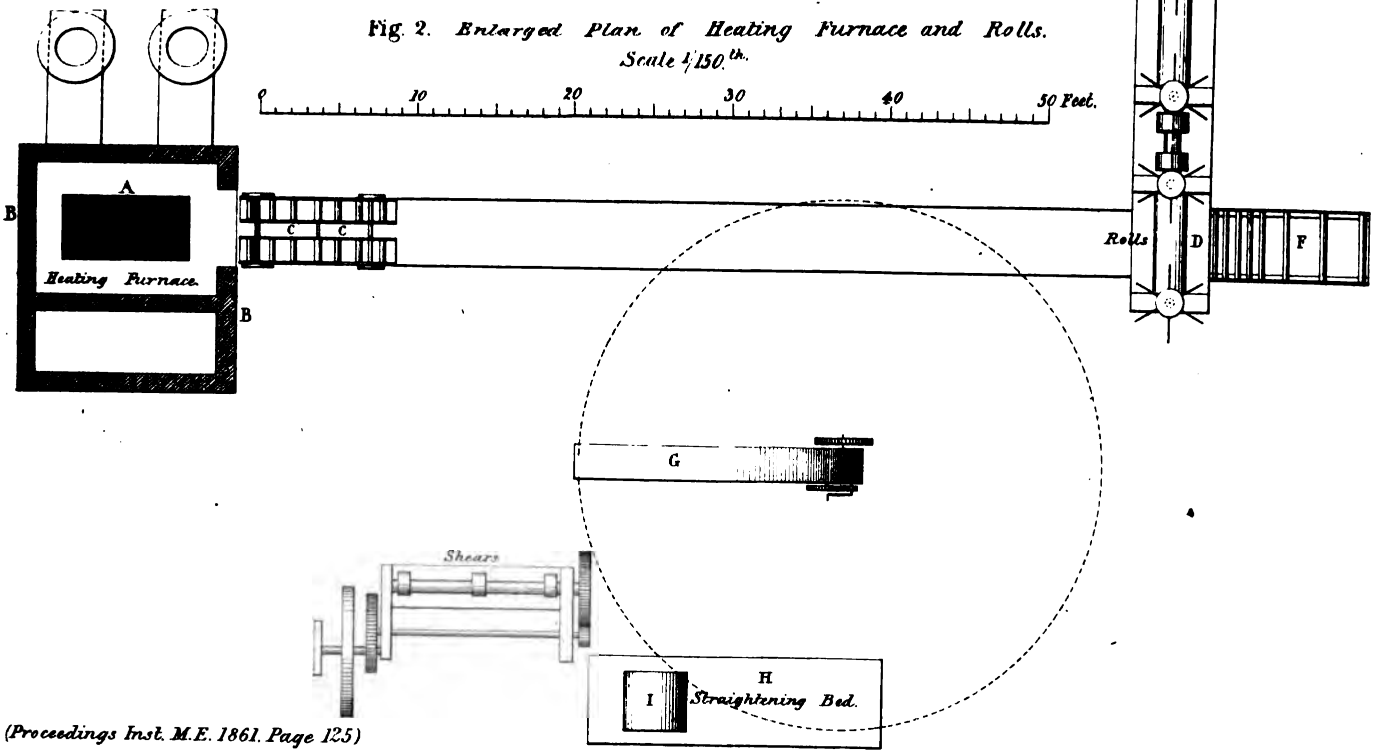
Fig. 1. General Plan of Armour Plate Mill.



(Proceedings Inst. M.E. 1861. Page 125)

ARMOUR PLATES.

Fig. 2. *Enlarged Plan of Heating Furnace and Rolls.*
Scale 1/150th.



(Proceedings Inst. M.E. 1861. Page 125)

ARMOUR PLATES.

Armour Plates tried in experiments.
Scale 1/50th.

Fig. 4.

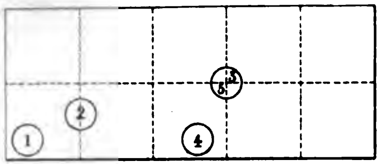


Fig. 5.

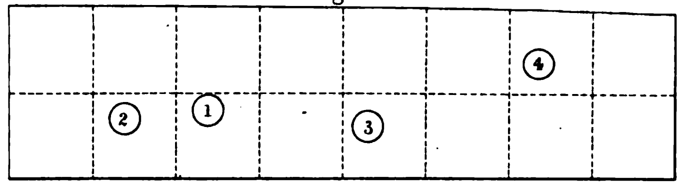
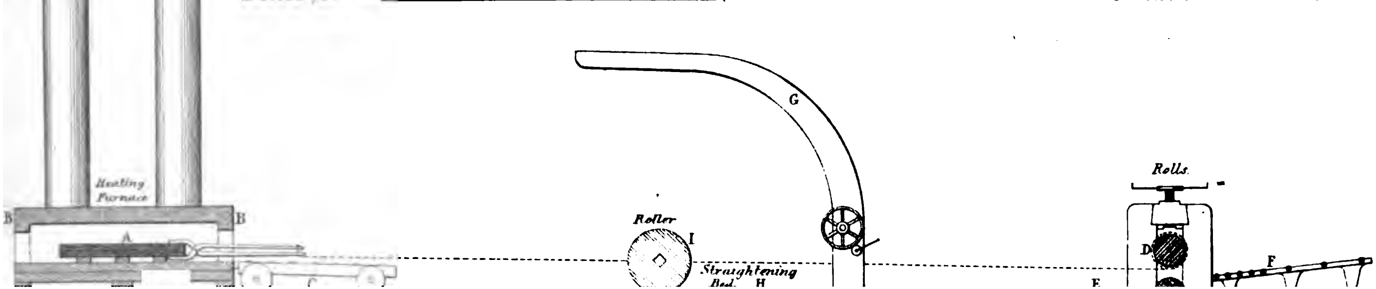


Fig. 3. *Elevation of Heating Furnace and Rolls.*

Scale 1/150th.



BESSEMER STEEL.

Fig 1. *Side Elevation of Converting Vessel, Casting Ladle, and Crane.*

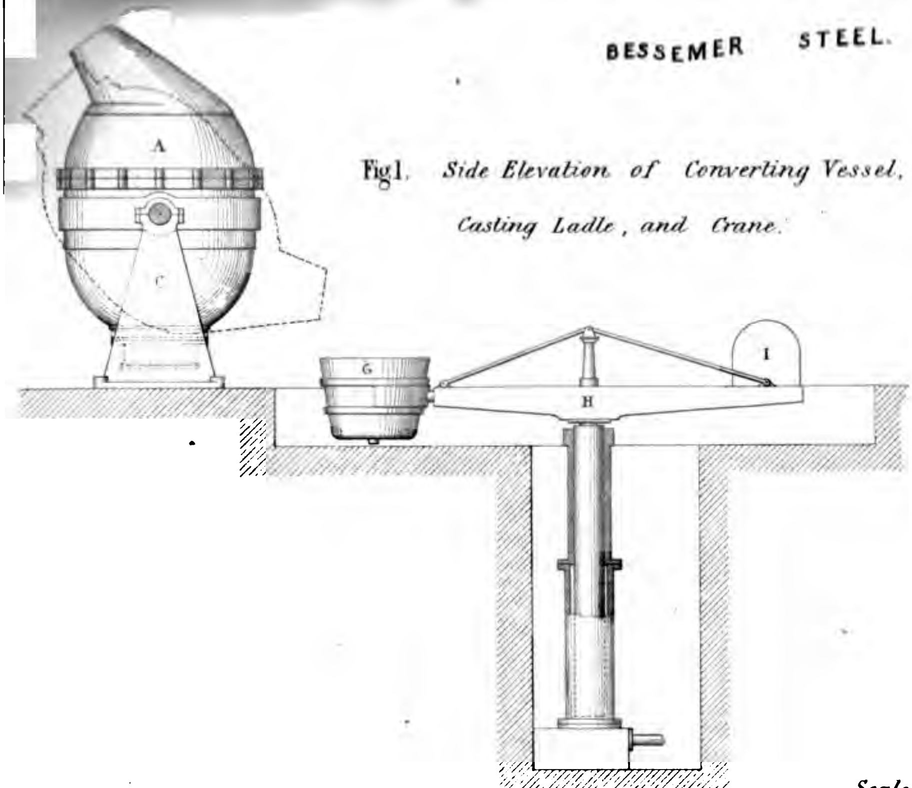
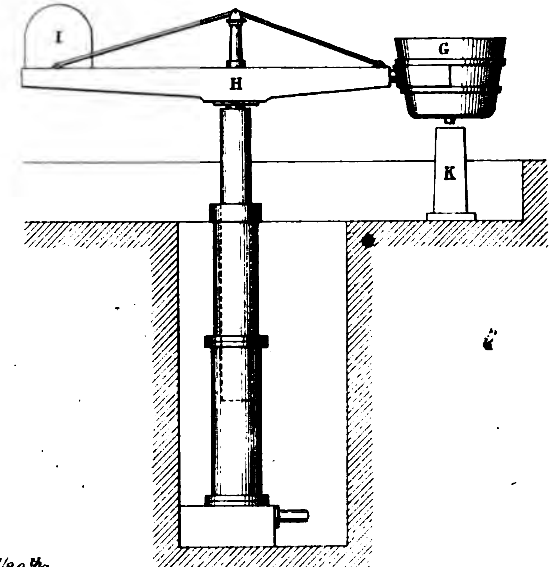
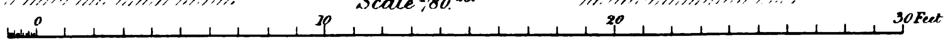


Fig. 2. *Casting the Steel into Ingots.*



Scale 1/80th.



(Proceedings Inst. M. E. 1861. Page 133.)

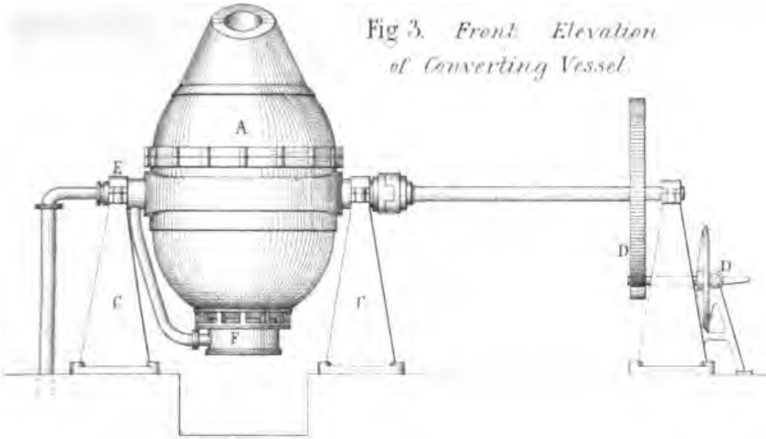


Fig 3. *Front Elevation of Converting Vessel.*

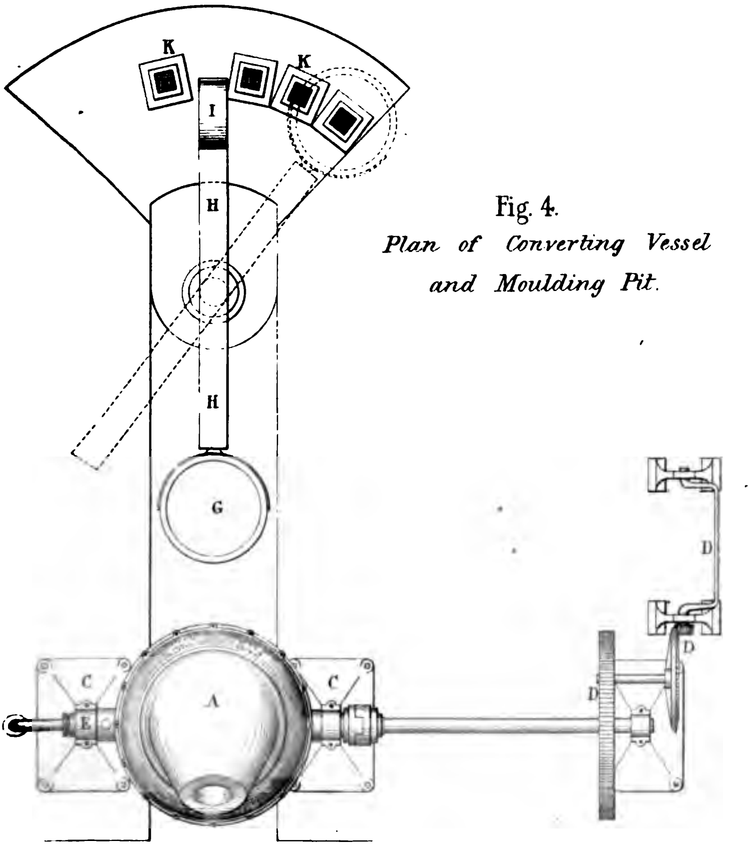


Fig. 4.
Plan of Converting Vessel and Moulding Pit.

Scale 1/80th. 0 5 10 15 20 *Feet.*
(Proceedings Inst. M.E. 1861. Page 133.)

BESSEMER STEEL.

Positions of Converting Vessel in filling and blowing.

Fig. 5. *Filling.*

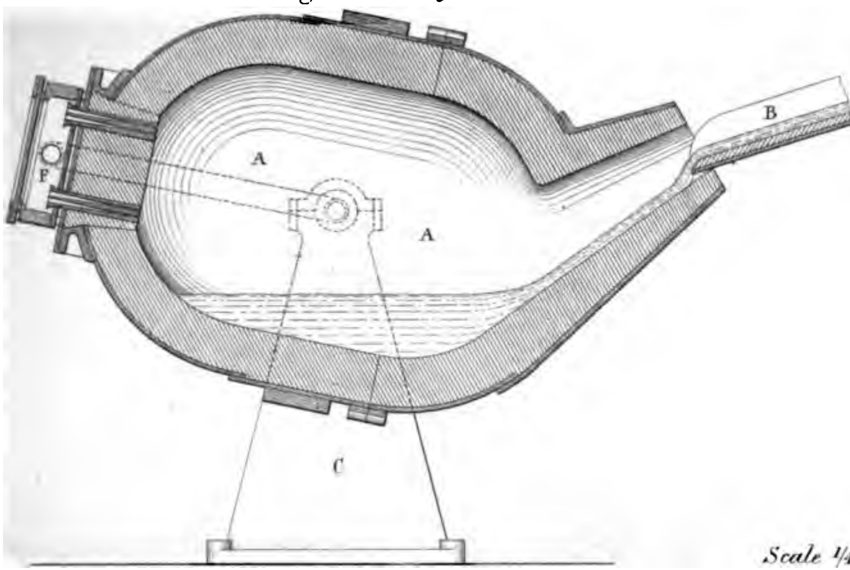
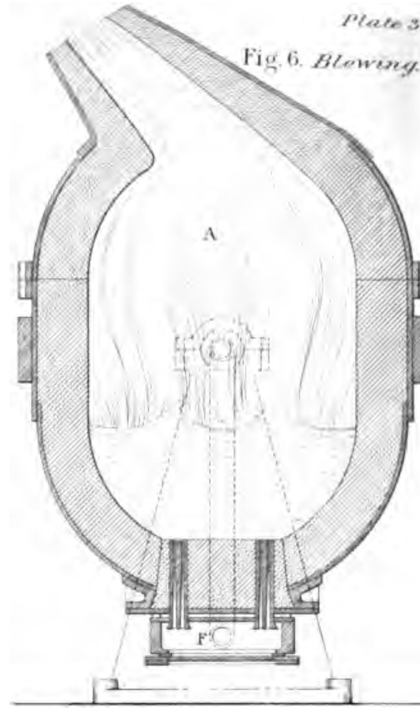


Fig. 6. *Blowing.*



Scale 1/40th.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

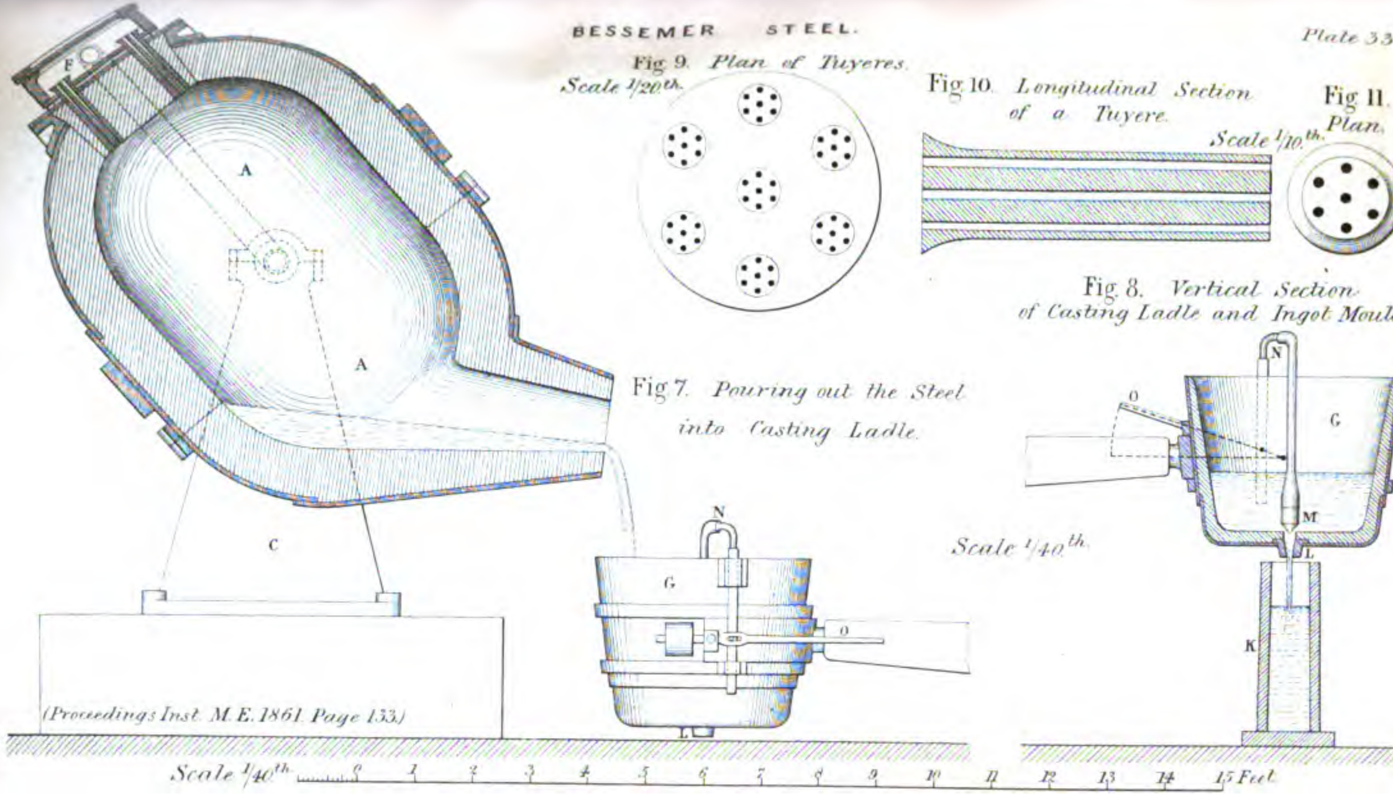


Fig 9. Plan of Tuyeres. Scale 1/20th.

Fig 10. Longitudinal Section of a Tuyere. Scale 1/10th.

Fig 11. Plan.

Fig 8. Vertical Section of Casting Ladle and Ingot Mould. Scale 1/40th.

Fig 7. Pouring out the Steel into Casting Ladle.

(Proceedings Inst. M. E. 1861. Page 133.)

STRENGTH OF STEEL.

Machine for testing Tensile strength.

Fig. 3. *End Elevation.*

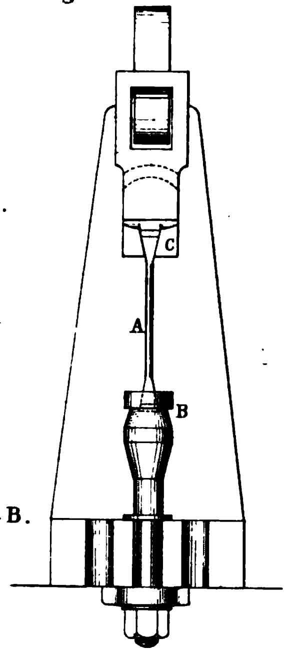


Fig. 2. *Side Elevation.*

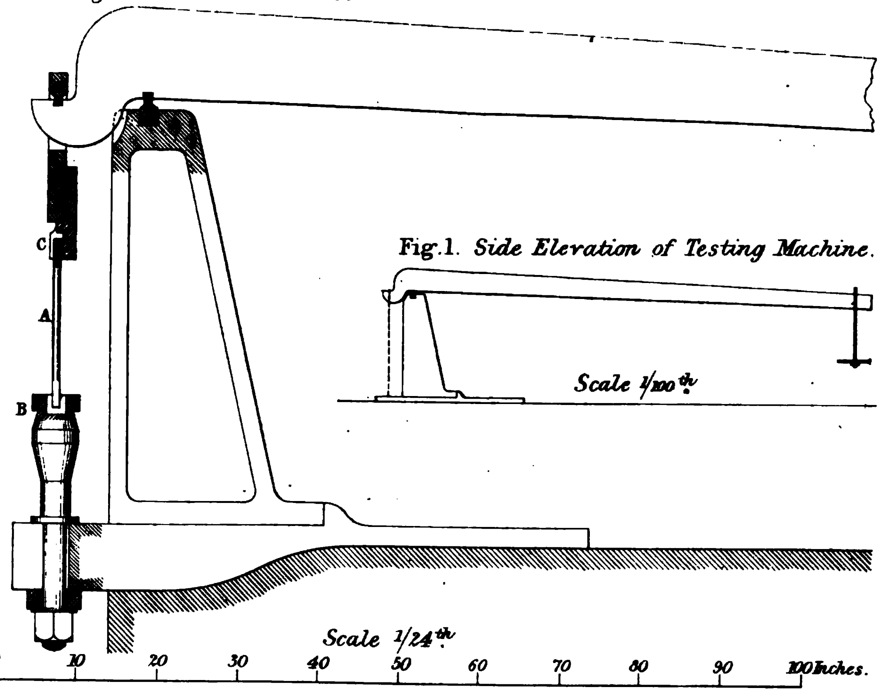


Fig. 1. *Side Elevation of Testing Machine.*

Scale 1/100th.

Test Bars.

Fig. 5. Fig. 4.

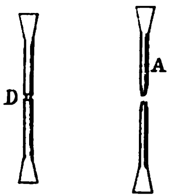


Fig. 6. *Plan of holding-down block* B.

STRENGTH OF STEEL.

Mode of testing Transverse strength of Cast Steel Axles.

Fig. 7.

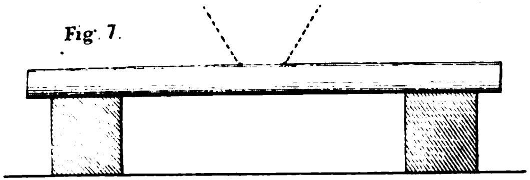


Fig. 8.

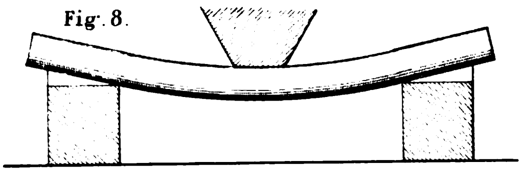


Fig. 9.

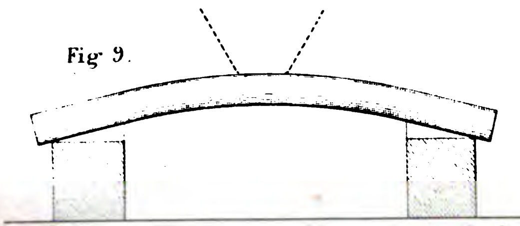
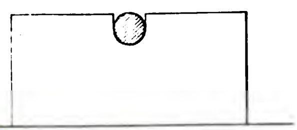
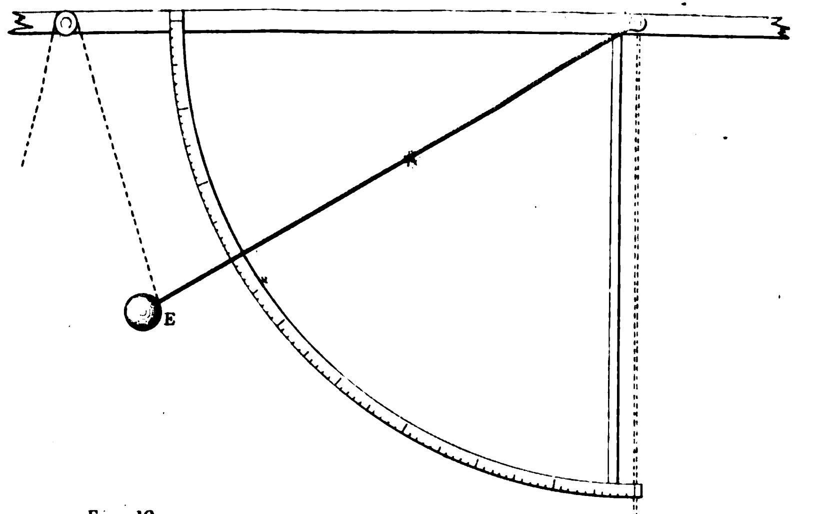


Fig. 10.



Scale 1/24th

Fig. 11. Mode of testing Cast Steel Disc Wheel.



Scale 1/100th

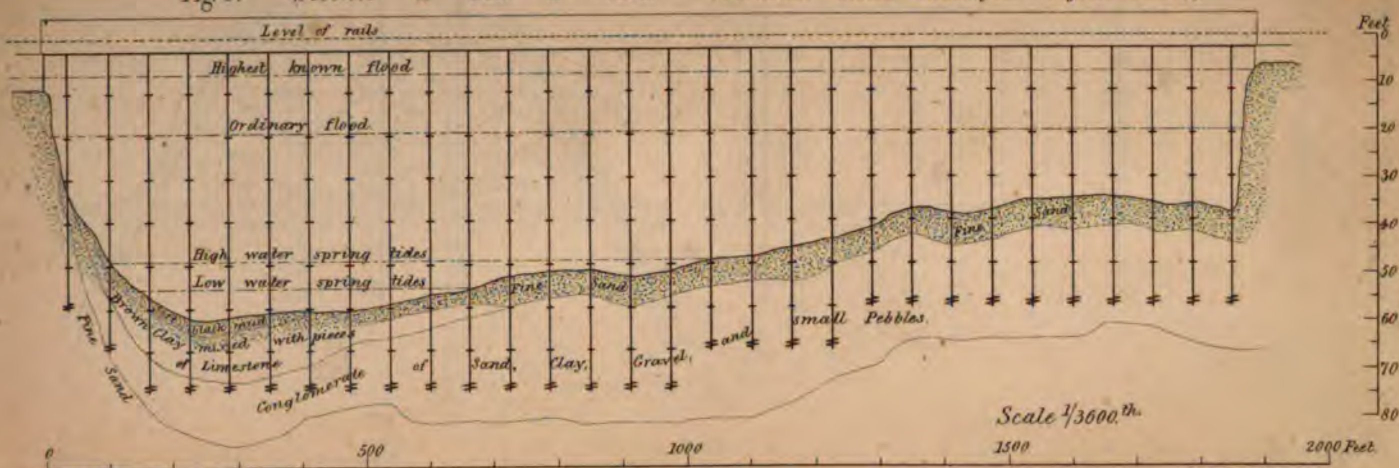
INDIAN RAILWAY BRIDGES.

Plate 36.

Fig. 1. General Elevation of Taptee Bridge, 1891 feet long.

Fig. 2. Transverse Section.

Fig. 3. Section of bed of river (vertical scale enlarged eight times.)



(Proceedings Inst. M. E. 1861. Page 171.)

INDIAN RAILWAY BRIDGES.

Fig. 4. Construction of Piers in strong tidal rivers.

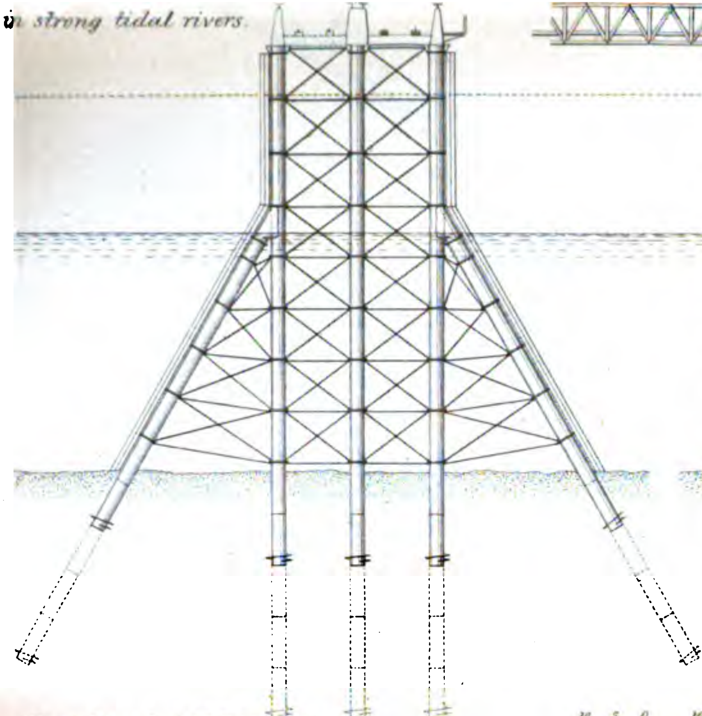


Fig. 5. Side Elevation of one span of bridge

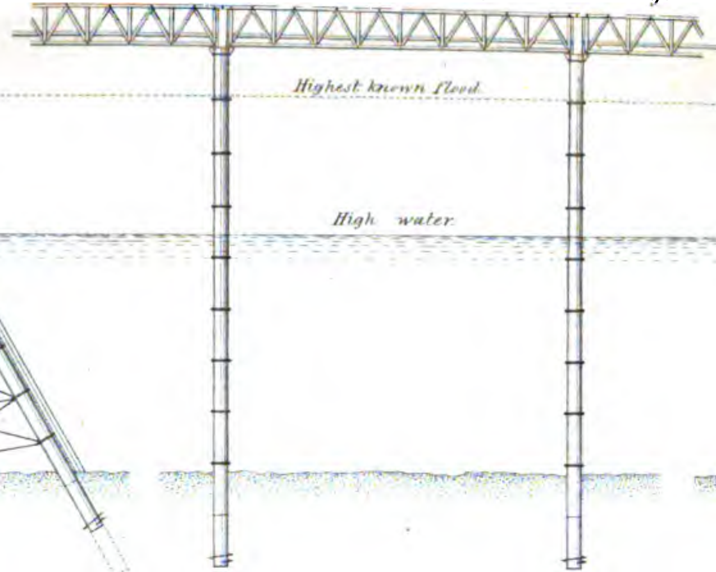
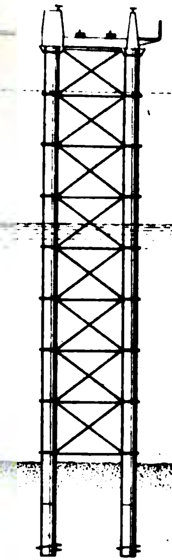


Fig. 6.

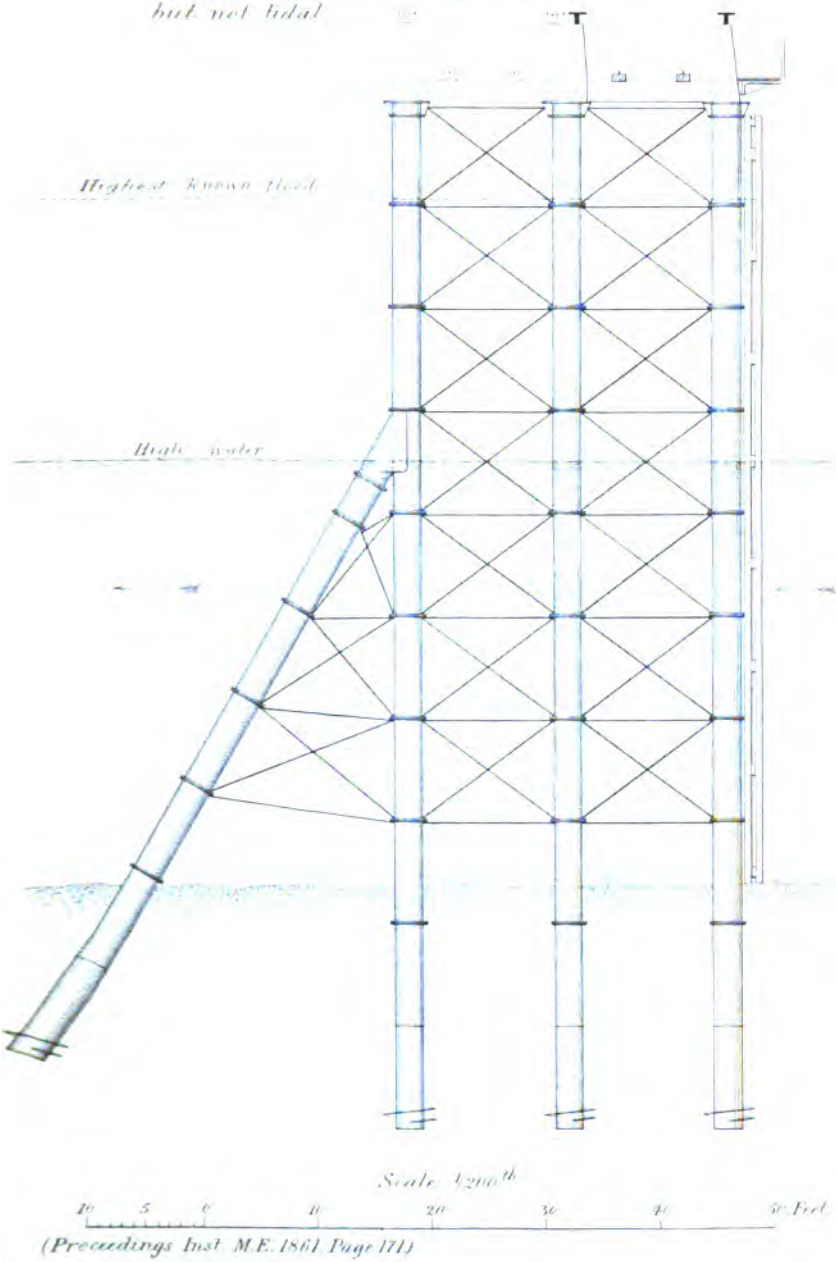


Scale 1/400th.

10 5 0 10 20 30 40 50 60 70 80 90 100 110 120 Feet.

(Proceedings Inst. M.E. 1861. Page 171.)

Fig. 7 *Construction of Piers in inland rivers with deep water but not tidal*



(Proceedings Inst. M.E. 1861. Page 171)

INDIAN RAILWAY BRIDGES.

Plate 39.

Fig. 8. Construction of Piers in inland rivers with shallow water.

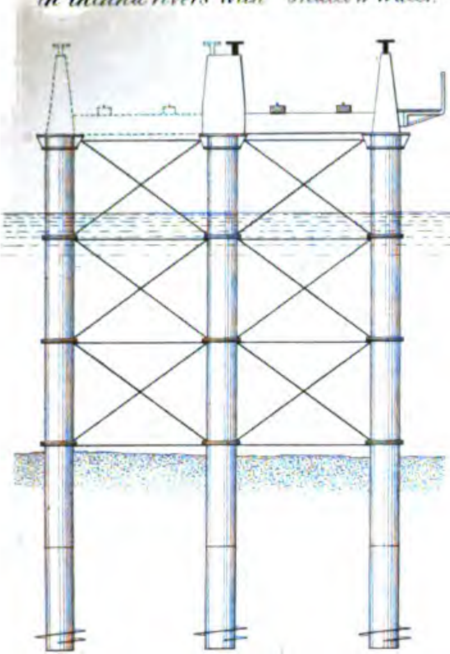


Fig. 9. Construction of Piers for rock foundations.

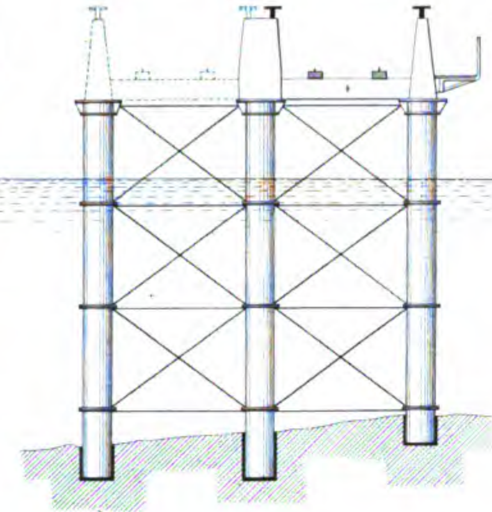
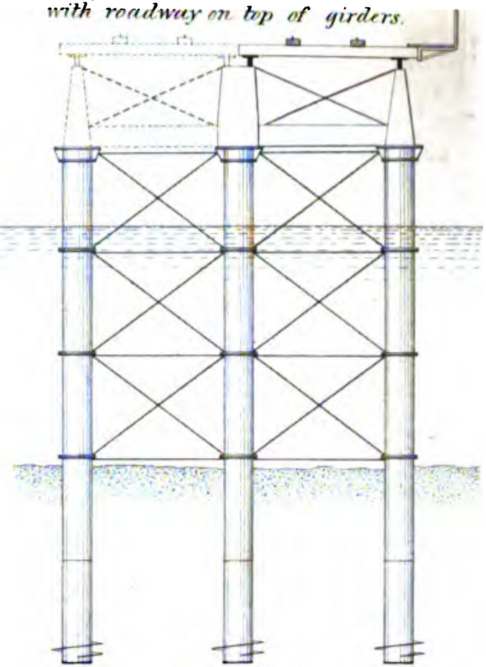


Fig. 10. Construction of Piers with roadway on top of girders.



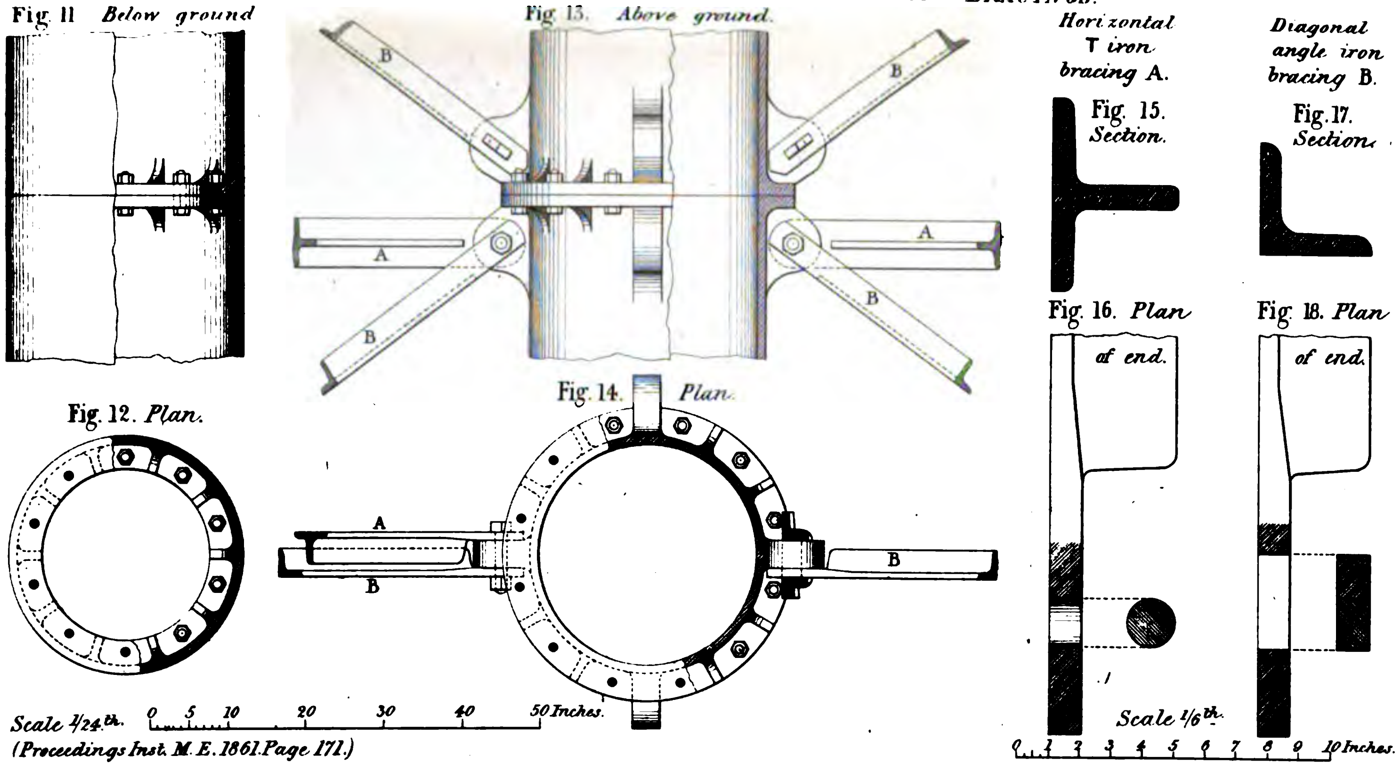
(Proceedings Inst. M.E. 1861. Page 171.)

Scale 1/200th. 10 5 0 10 20 30 40 50 Feet.

INDIAN RAILWAY BRIDGES.

JOINTS OF PILES AND ATTACHMENT OF BRACINGS.

Plate 40.



(Proceedings Inst. M. E. 1861. Page 171.)

INDIAN RAILWAY BRIDGES.

Fig. 19. *Side Elevation of one span of Superstructure.*

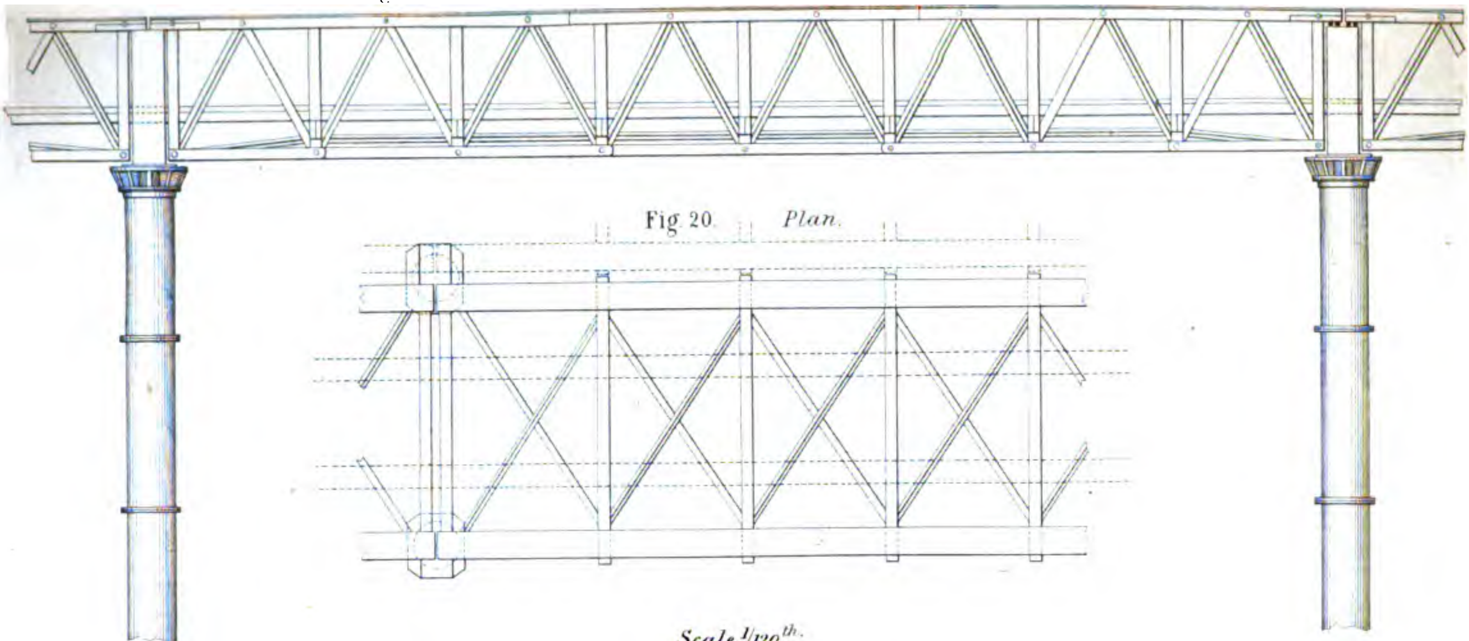


Fig. 20. *Plan.*

Scale 1/120th.

0 5 10 20 30 40 50 60 Feet.

(Proceedings Inst. M.E. 1861. Page 171.)

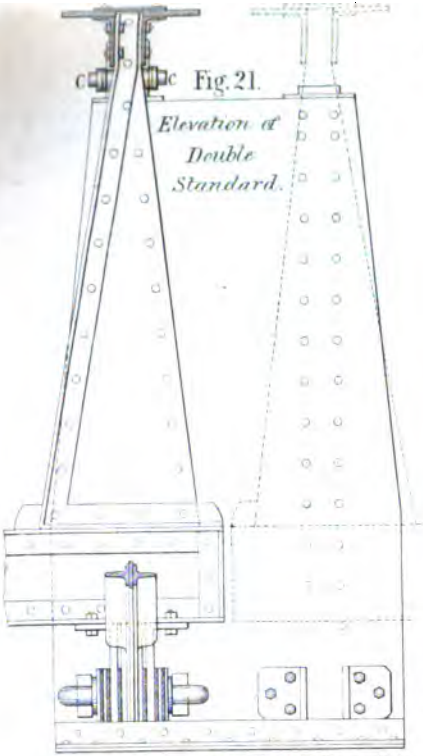


Fig. 21.

Elevation of Double Standard.

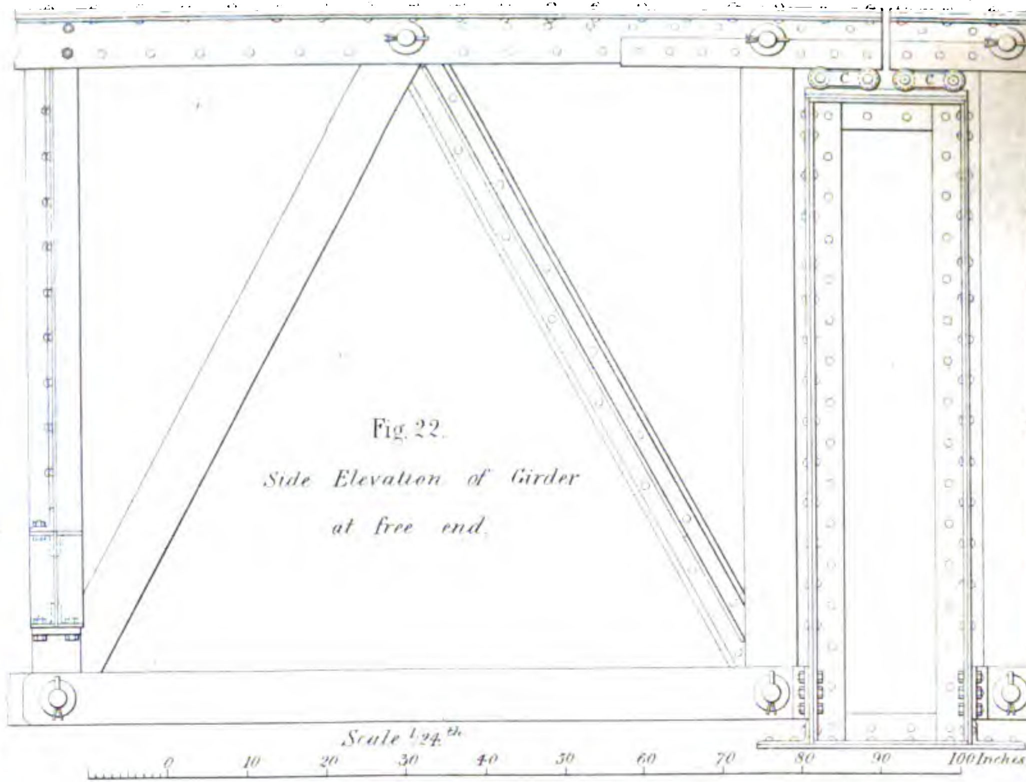


Fig. 22.

Side Elevation of Girder at free end.

(Proceedings Inst. M.E. 1861. Page 171.)

INDIAN RAILWAY BRIDGES.

SECTIONS OF GIRDERS.

Fig. 23. Top Compression Beam. Section at end.

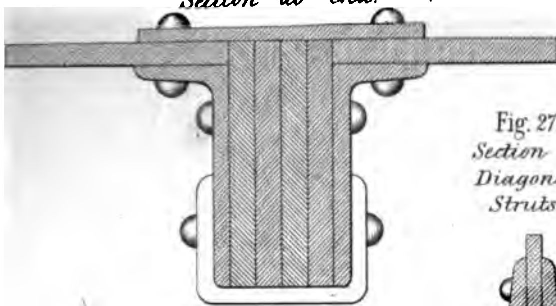


Fig. 24. Top Compression Beam. Section at middle.

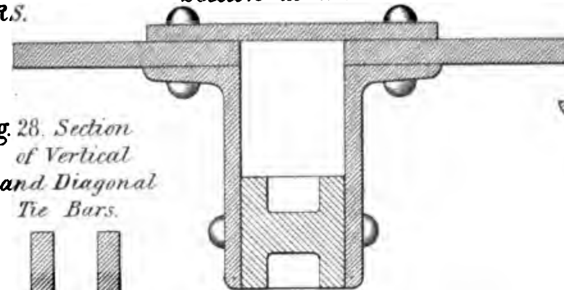


Fig. 27. Section of Diagonal Struts.

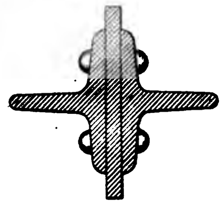


Fig. 28. Section of Vertical and Diagonal Tie Bars.

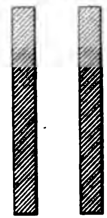


Fig. 29. Section of Roadway Girder.

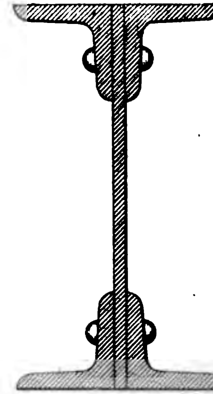
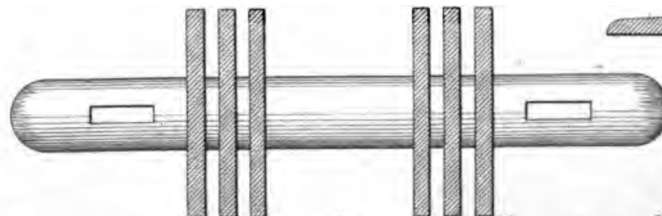


Fig. 25. Bottom Tie Bars. Section at end.

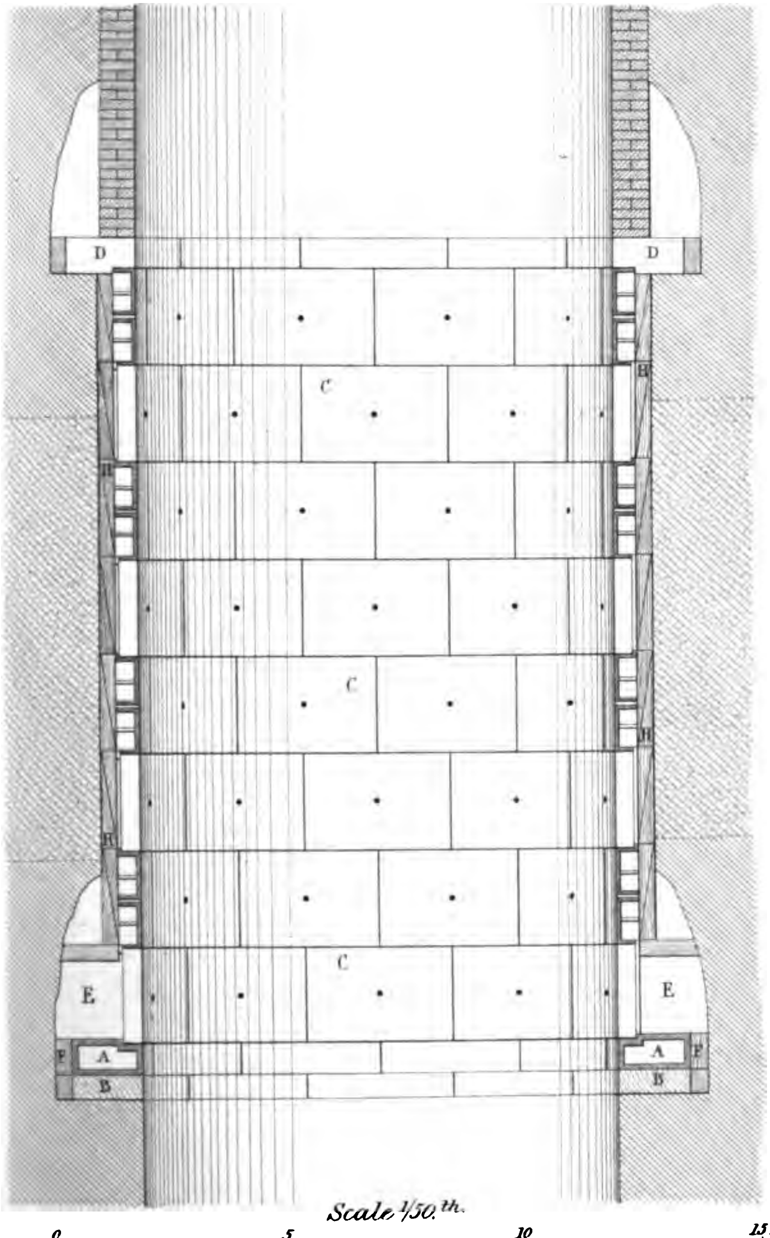
Fig. 26. Bottom Tie Bars. Section at middle.



Scale 1/6th. 0 5 10 15 20 Inches.

(Proceedings Inst. M.E. 1861. Page 171.)

Fig. 1. *Vertical Section of Shaft with Tubbing.*



Scale 1/50th.

(Proceedings Inst. M.E. 1861. Page 193)

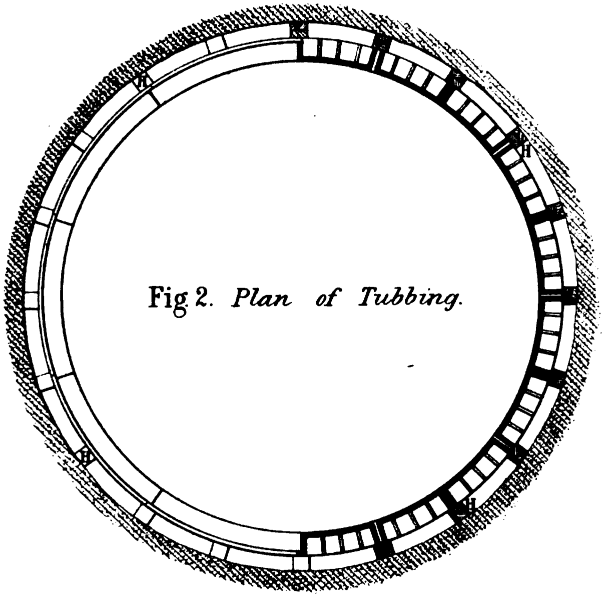


Fig. 2. *Plan of Tubbing.*

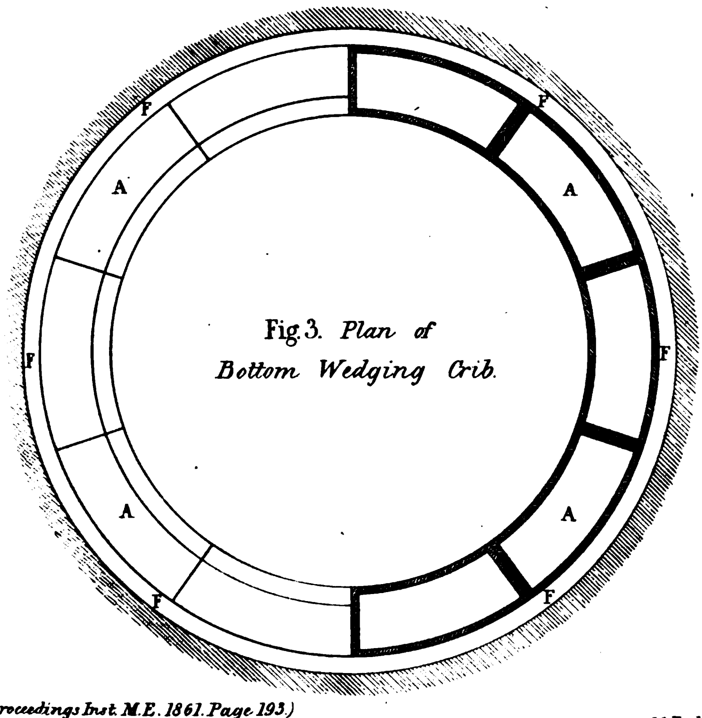


Fig. 3. *Plan of Bottom Wedging Crib.*

(Proceedings Inst. M.E. 1861. Page 193.)

Scale 1/50th 0 5 10 Feet.

Fig. 4. *Back Elevation of Tubbing Plate.*

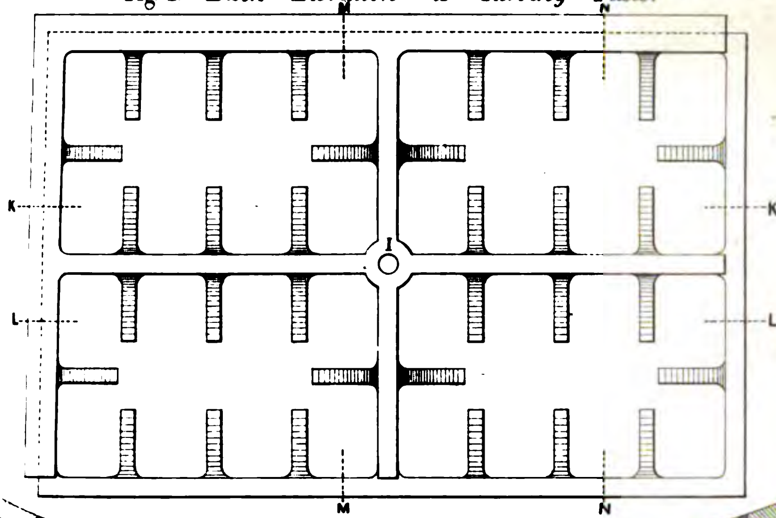


Fig. 5. *Horizontal Section at* KK.

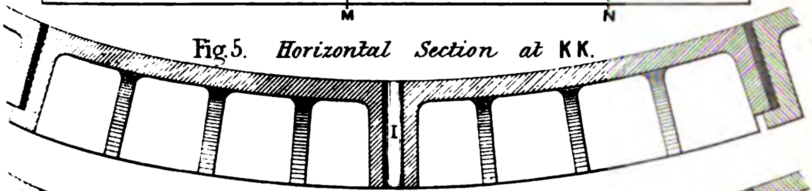
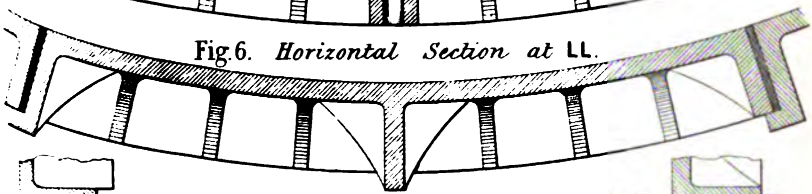


Fig. 6. *Horizontal Section at* LL.



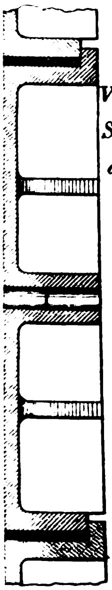


Fig. 7. *Vertical Section at* MM.

Fig. 9. *Section of Bottom Wedging Crib.*

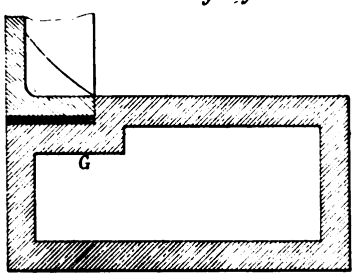
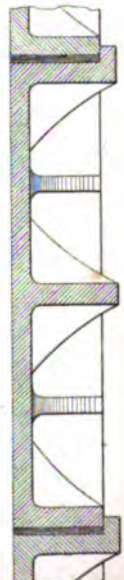
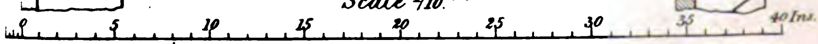


Fig. 8. *Vertical Section at* NN.



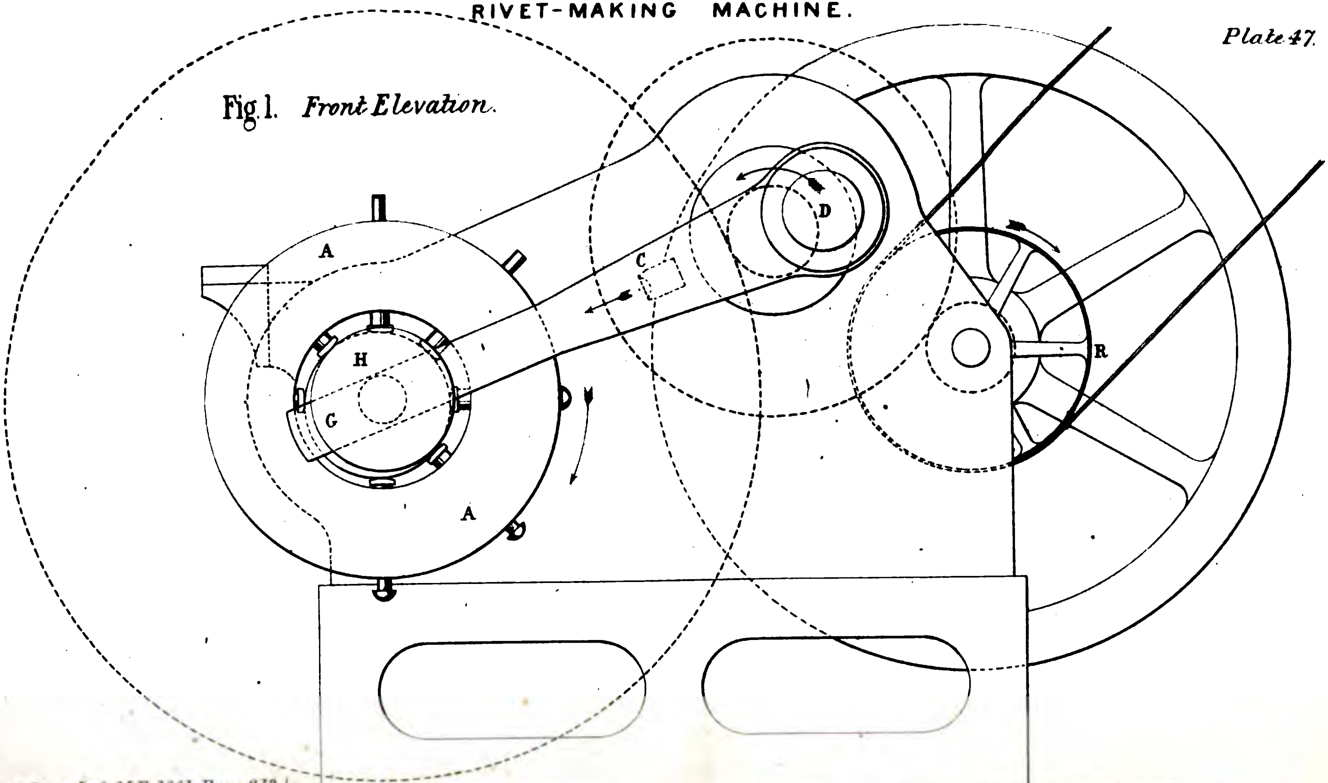
(Proceedings Inst. M.E. 1861. Page 193.)

Scale 1/10th.



RIVET-MAKING MACHINE.

Fig. 1. *Front Elevation.*

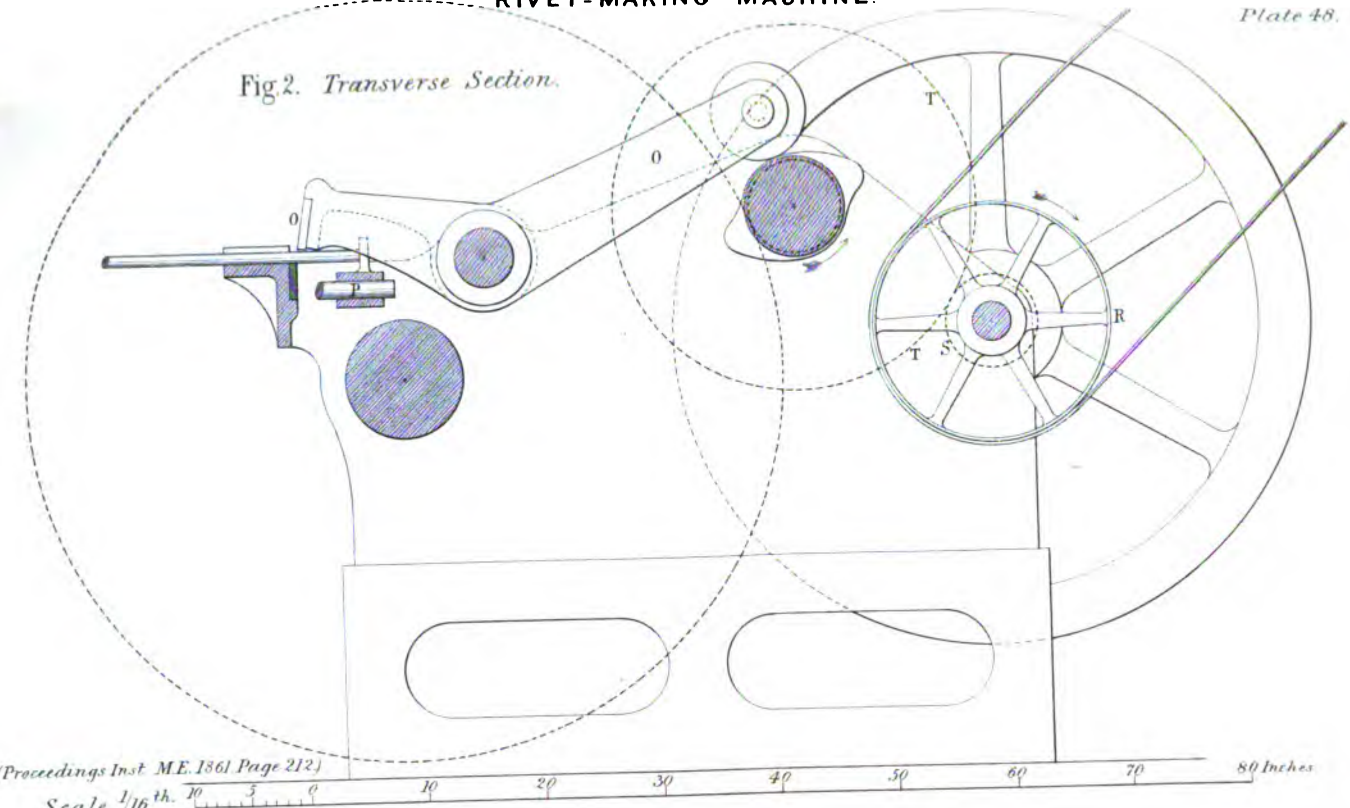


(*Proceedings Inst. M.E. 1861. Page 212.*)

Scale 1/16th. 10 5 0 10 20 30 40 50 60 70 80 *Inches.*

RIVET-MAKING MACHINE.

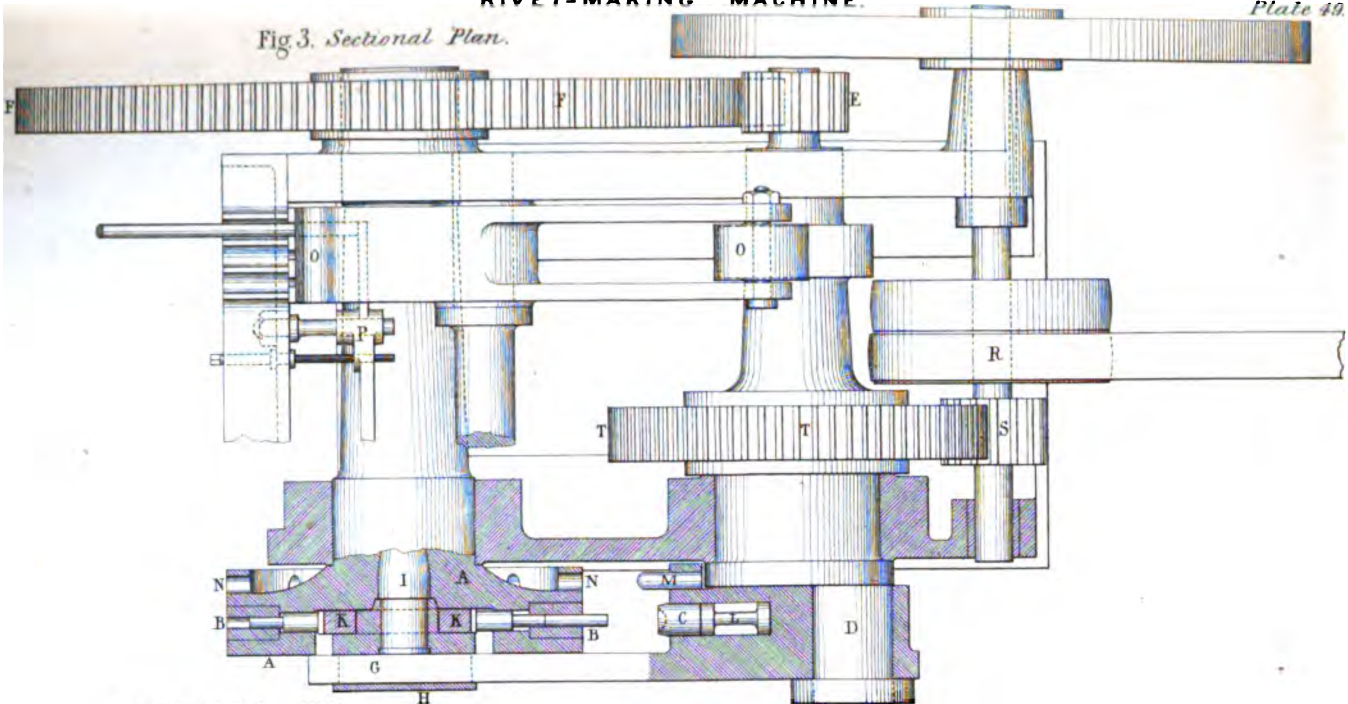
Fig. 2. *Transverse Section.*



(Proceedings Inst. M.E. 1861 Page 212)

RIVET-MAKING MACHINE.

Fig. 3. *Sectional Plan.*



Scale 1/16th. 10 5 0 10 20 30 40 50 60 70 80 Inches.

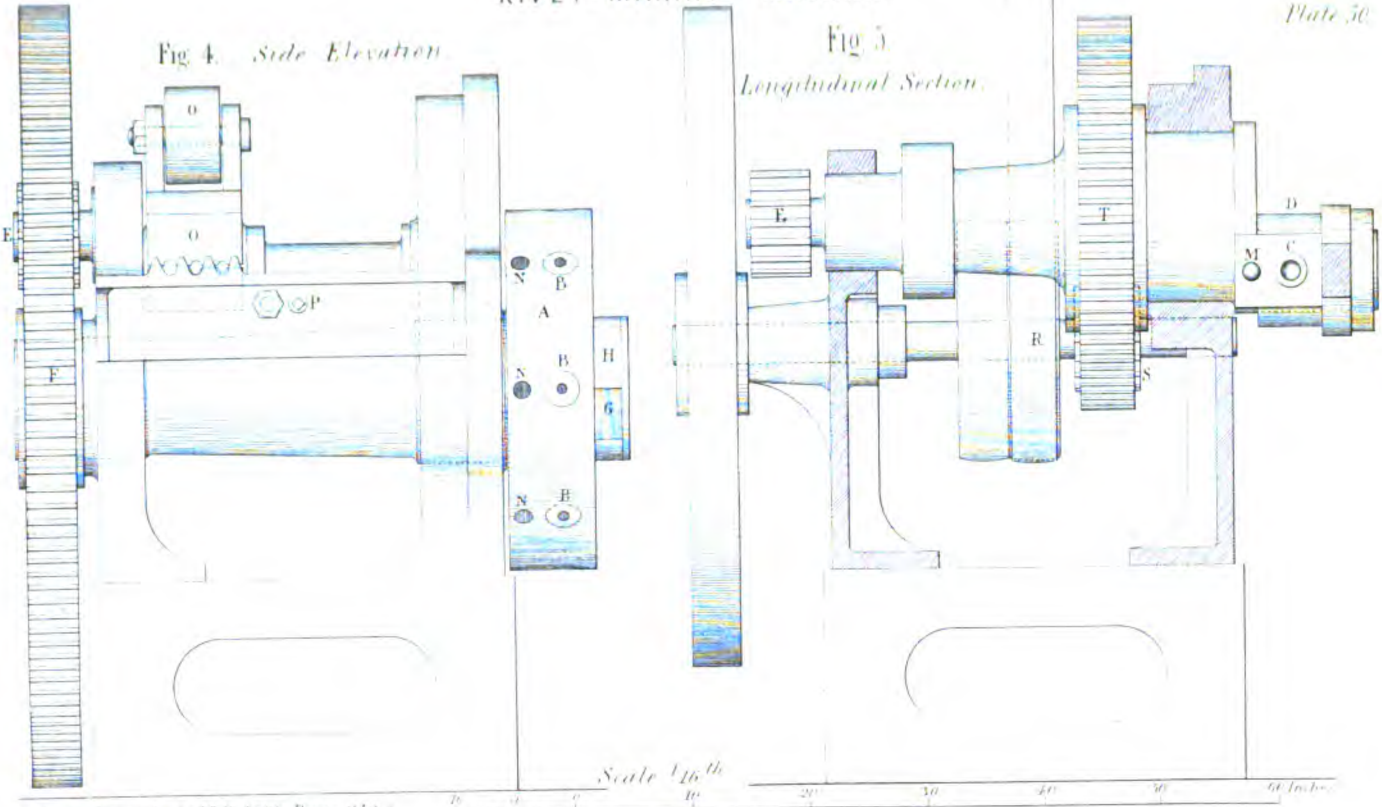
(Proceedings Inst. M. E. 1861. Page 212.)

RIVET-MAKING MACHINE

Plate 50.

Fig 4. Side Elevation

Fig 5. Longitudinal Section



RIVET-MAKING MACHINE.

Fig. 6.

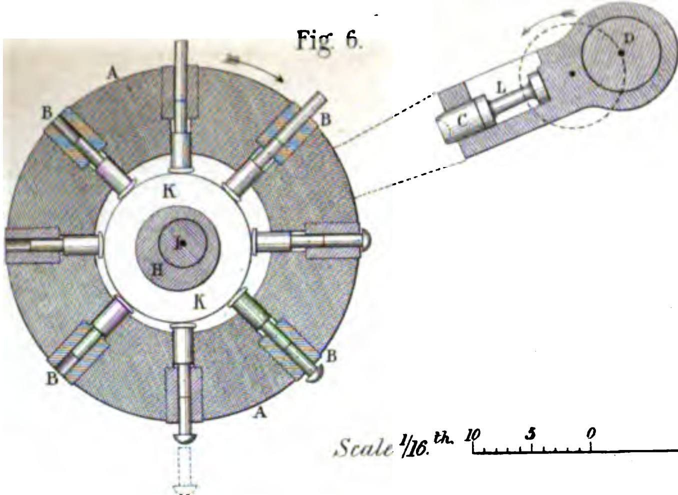
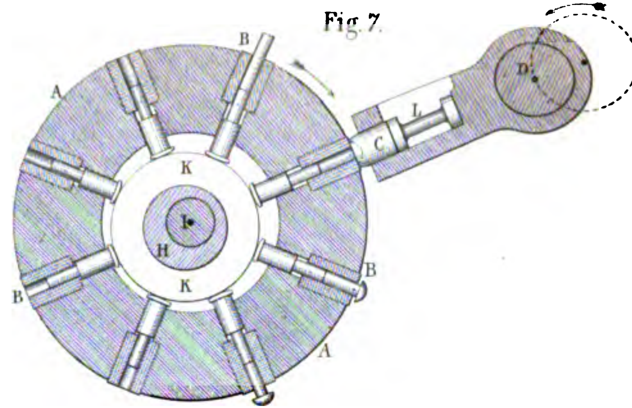
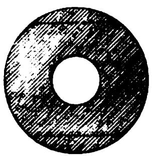


Fig. 7.



Scale 1/16.th 10 5 0 10 20 30 40 50 Inches.

Fig. 8. Die. Fig. 9.



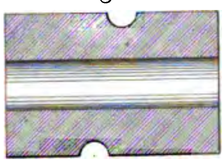
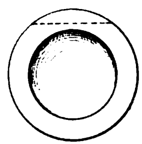


Fig. 10. Header. Fig. 11.



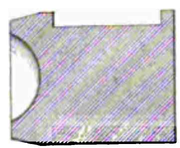
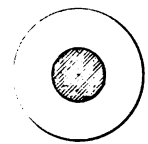
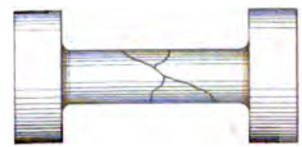


Fig. 12. Crushing Piece. Fig. 13.





Scale 1/4.th 0 5 10 Inches.

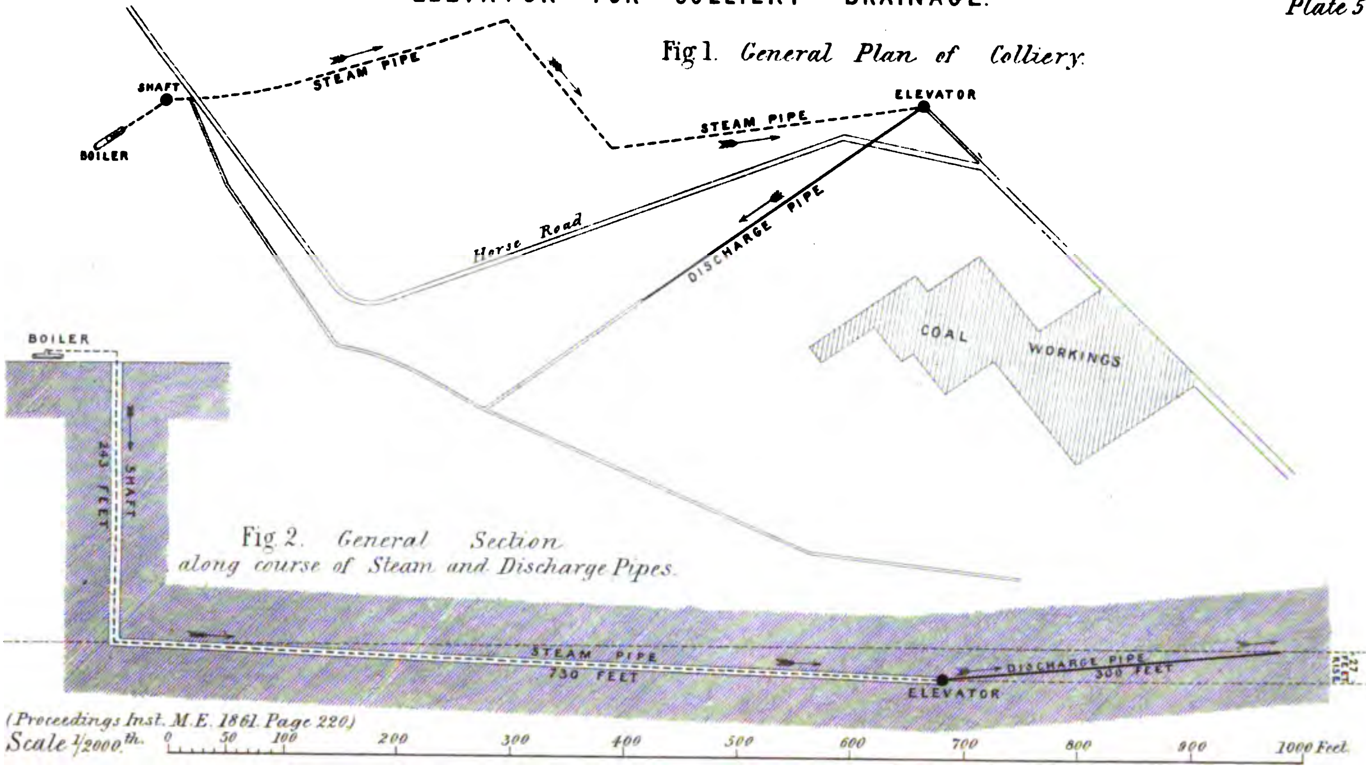
(Proceedings Inst. M.E. 1861. Page 212.)

ELEVATOR FOR COLLIERY DRAINAGE.

Plate 52.

Fig 1. *General Plan of Colliery.*

Fig 2. *General Section along course of Steam and Discharge Pipes.*



(Proceedings Inst. M.E. 1861. Page 220)

Scale 1/2000th.

Fig. 3. *Arrangement of Elevator in pit.*

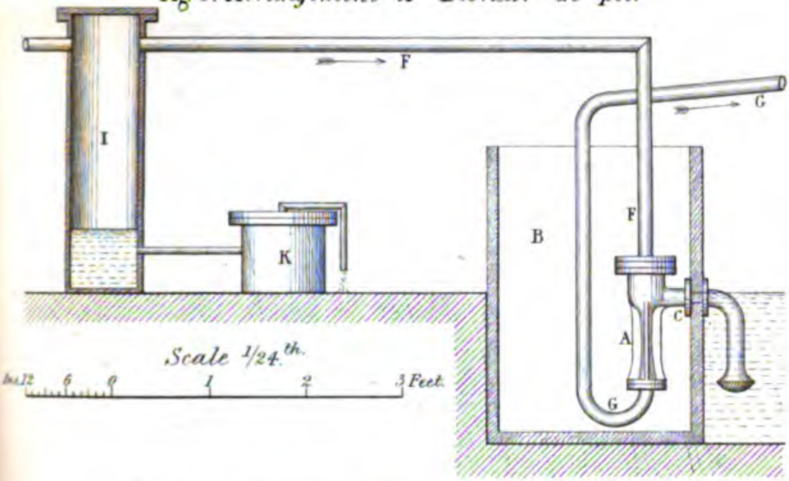
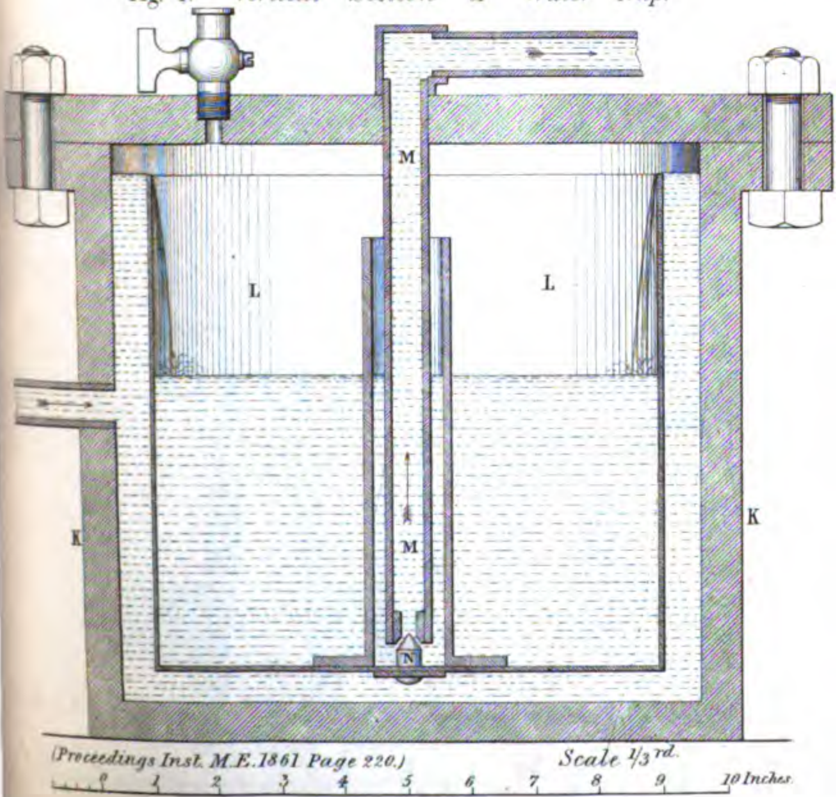


Fig. 4. *Vertical Section of Water Trap.*



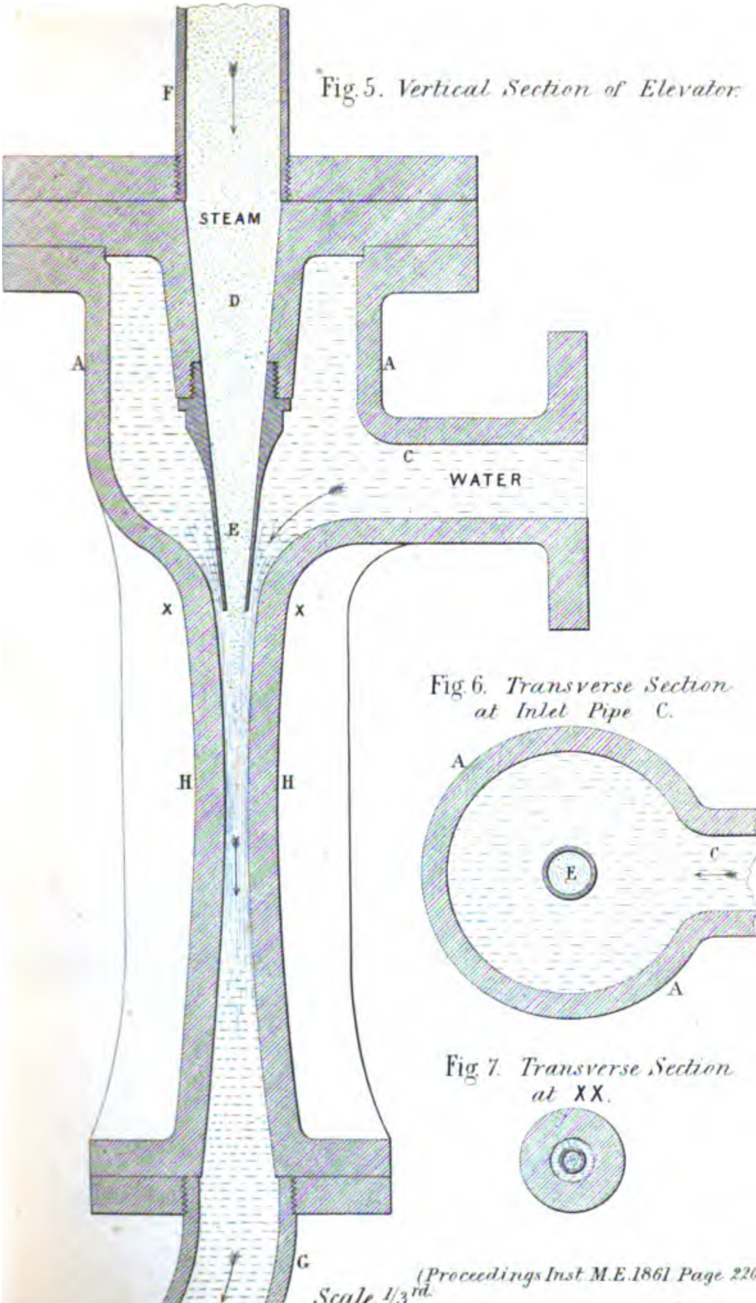


Fig. 5. *Vertical Section of Elevator.*

Fig. 6. *Transverse Section at Inlet Pipe C.*

Fig. 7. *Transverse Section at XX.*

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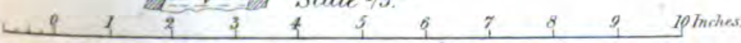
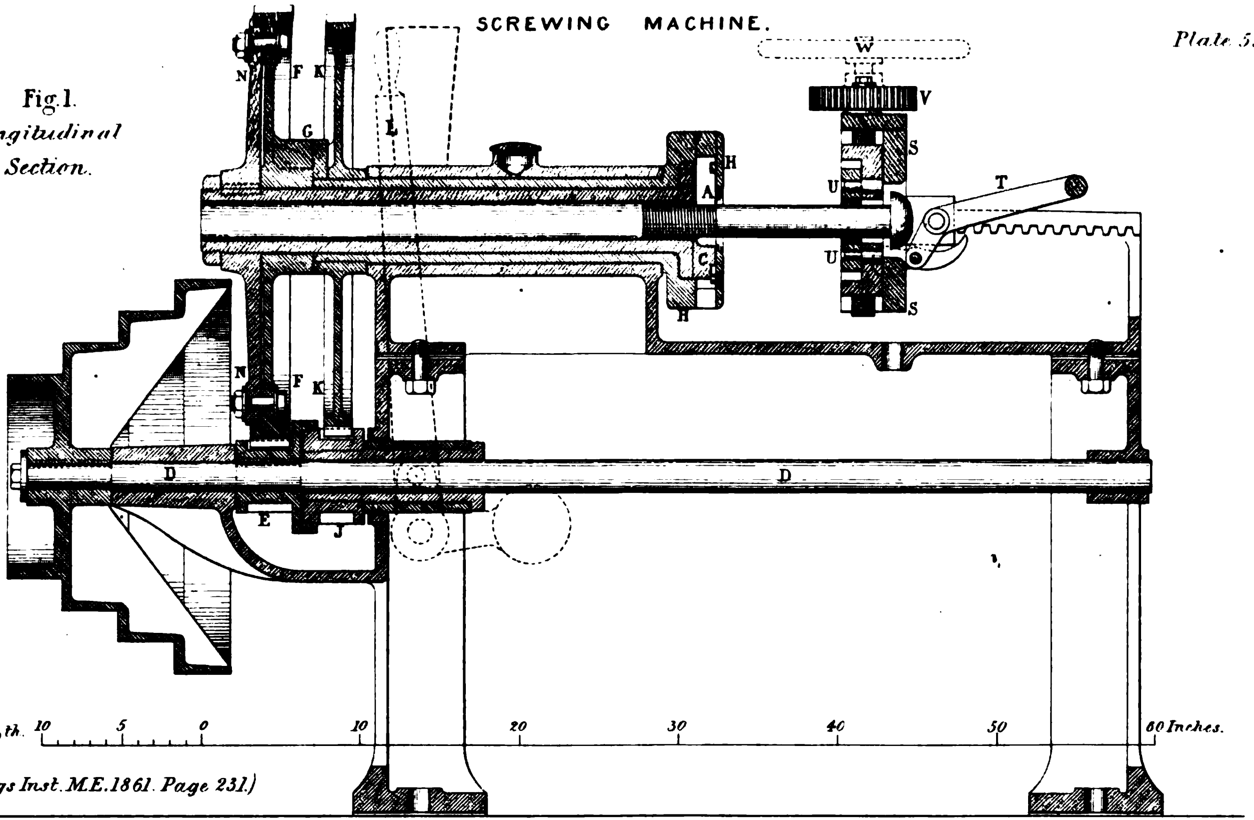
Scale 1/3rd.



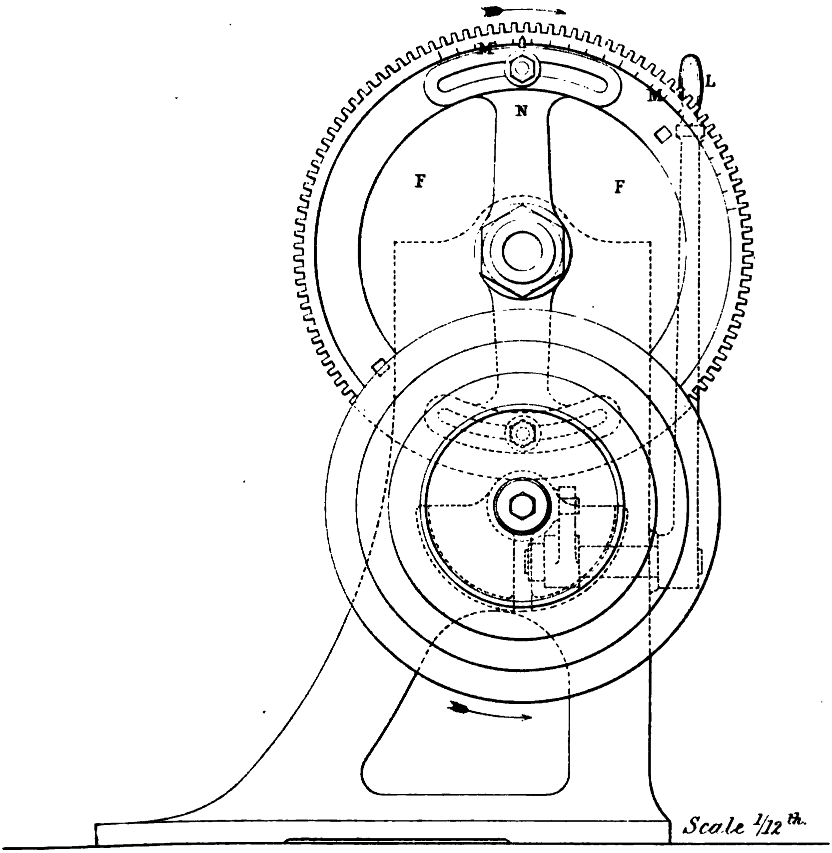
SCREWING MACHINE.

Fig. 1.
Longitudinal Section.



(Proceedings Inst. M.E. 1861. Page 231.)

Fig. 2. *End Elevation.*



Scale 1/12th.

Fig. 4.
Holding Clamps.
Scale 1/6th.

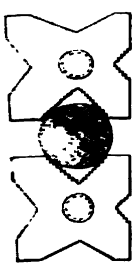
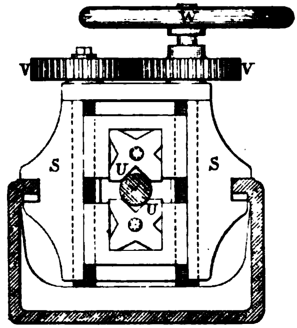


Fig. 3. *Elevation of Sliding Holder.*



Scale 1/12th.

10 5 0 10 20 30 *Inches.*

(*Proceedings Inst. M. E. 1861. Page 231.*)

Plate 57.

SCREWING MACHINE.

Fig. 5. *Longitudinal Section of Die Box.*

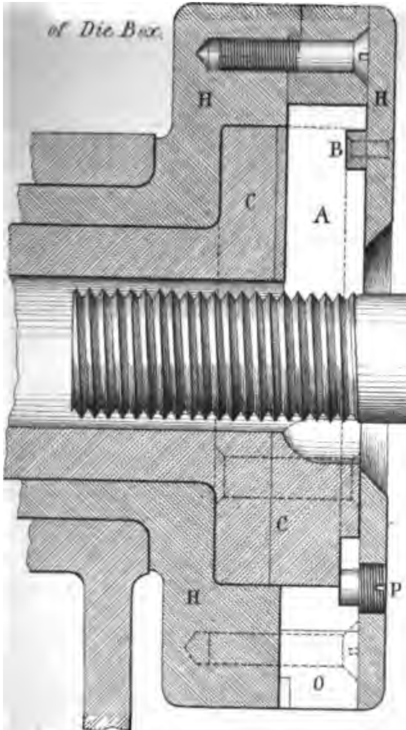


Fig. 7. *Cutting Die.*

Fig. 6. *Front Elevation of Die Box with cover plate removed.*

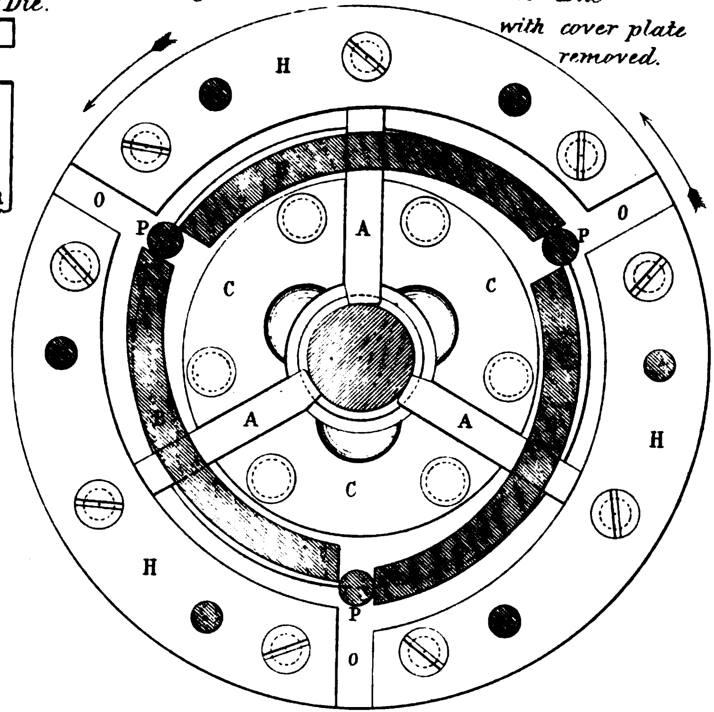
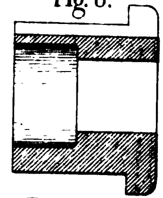
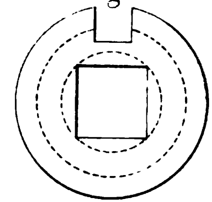


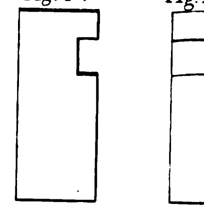
Fig. 8.



Tap Holder.
Fig. 9.



Key for fixing Tap Holder.
Fig. 10. Fig. 11.



Scale 1/3rd.

(*Proceedings Inst. M. E. 1861. Page 231.*)

INSTITUTION

OF

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PROCEEDINGS.

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LIVERY STREET.

INDEX.

1862.

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WITH YEAR OF ELECTION.

1862.

LIFE MEMBERS.

1852. Brogden, Henry, Sale, near Manchester.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven.
1857. Haughton, S. Wilfred, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
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1856. Allen, Edward Ellis, 5 Parliament Street, Westminster, S.W.
1856. Allen, James, Cambridge Street Works, Manchester.
1859. Alton, George, Midland Railway Works, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
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1859. Armitage, William James, Farnley Iron Works, Leeds.

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1848. Bagnall, William, Gold's Hill Iron Works, Westbromwich.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1848. Baker, William, London and North Western Railway, Euston Station, London, N.W.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1862. Barrow, Joseph, Wellington Foundry, Leeds.
1862. Barton, Edward, Rutland Steel Works, Sheffield.
1847. Barwell, William Harrison, Eagle Foundry, Northampton.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Bordesley Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, Parkgate Iron Works, Rotherham.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
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1860. Beck, Richard, Lister Works, Upper Holloway, London, N.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1858. Bell, Isaac Lothian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1854. Bennett, Peter Duckworth, Spon Lane Iron Works, Westbromwich.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
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1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Russell's Hall Iron Works, near Dudley.
1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.
1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.
1862. Bouch, Thomas, 78 George Street, Edinburgh.
1858. Bouch, William, Shildon Engine Works, Darlington.
1847. Bovill, George Hinton, Durnsford Lodge, Wandsworth, Surrey, S.W.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.
1862. Boyd, Nelson, Mining Engineer, Hartington, near Ashbourne.
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1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.
1856. Bray, Edwin, Nevill Holt, near Market Harborough.
1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel Works, Sheffield.
1855. Brown, John, Mining Engineer, Barnsley.
1856. Brown, John, Mining Engineer, Bank Top, Darlington.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1858. Burn, Henry, Midland Railway, Locomotive Department, Sheffield.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.
1859. Butler, John, Old Foundry, Stanningley, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Midland Great Western Railway, Dublin
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1856. Carrett, William Elliott, Sun Foundry, Leeds.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1849. Chamberlain, Humphrey, 3 St. John's, Wakefield.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1847. Clift, John Edward, Durnford Place, Coventry Road, Birmingham.
1860. Clunes, Thomas, Vulcan Iron Works, Worcester.
1847. Cochrane, Alexander Brodie, Woodside Iron Works, near Dudley.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesborough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1847. Coke, Richard George, Mining Engineer, 6 Market Hall Chambers, Chesterfield.

1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, Locomotive Superintendent, Great Indian Peninsula Railway, Bombay: (or care of T. D. Hornby, 4 Exchange Buildings, Liverpool.)
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1860. Cowie, David, Engine Works, Abo, Finland.
1847. Cowper, Edward Alfred, 35A Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 6 St. John's Road, Putney, London, S.W.
1853. Craig, William Grindley, 14 Cannon Street, London, E.C.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1857. Criswick, Theophilus, Plymouth Iron Works, Merthyr Tydvil.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, Engineer, West Hetton Collieries, near Ferryhill.
1862. Deakin, William, Monmer Lane Iron Works, Willenhall, near Wolverhampton.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1861. Dixon, Thomas, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Dodds, Thomas W., Holmes Engine Works, Rotherham.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1856. Dudgeon, John, Sun Iron Works, Millwall, London, E.
1856. Dudgeon, William, Sun Iron Works, Millwall, London, E.
1857. Dunlop, John Macmillan, Marlborough Street, Oxford Street, Manchester.
1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.

1859. Eassie, Peter Boyd, Saw Mills, High Orchard, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1859. Egleston, Thomas, Jun., 10 Fifth Avenue, New York.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.

1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1858. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.

1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1862. Farmer, John, Shut End Iron Works, near Dudley.
1861. Fearnley, Thomas, Globe Works, Hall Lane, Bradford, Yorkshire.
1847. Fenton, James, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Fernie, John, Midland Railway, Locomotive Department, Derby.
1862. Field, Joshua, 6 Cheltenham Place, Lambeth, London, S.
1861. Field, Joshua, Jun., Cheltenham Place, Lambeth, London, S.
1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.
1847. Fothergill, Benjamin, 65 Cannon Street, London, E.C.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1857. Fowler, John, Steam Plough Works, Leeds.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1859. Fraser, John, Resident Engineer, Leeds Bradford and Halifax Junction Railway, Leeds.
1858. Fraser, Joseph Boyes, Alma Place, Kenilworth.
1856. Freeman, Joseph, 22 Cannon Street, London, E.C.
1852. Froude, William, Elmsleigh, Paignton, Torquay.

1862. Galton, Capt. Douglas, R. E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1860. Gibbons, Benjamin, Jun., Athol House, Edgbaston, Birmingham.
1856. Gilkes, Edgar, Tees Engine Works, Middlesborough.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesborough.

1854. Goode, Benjamin W., St. Paul's Square, Birmingham.
1847. Goodfellow, Benjamin, Hyde Iron Works, Hyde, near Manchester.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., 3 Bank Street, Exchange, Manchester.
1858. Greenwood, Thomas, Albion Foundry, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.

1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1857. Hall, William, Bloomfield Iron Works, Tipton.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, North Eastern Railway, Newcastle-on-Tyne.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1861. Hawkins, William Bailey, 38 Dowgate Hill Chambers, Cannon Street, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1862. Haynes, Thomas John, Engineer and Shipbuilder, Cadiz.
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1858. Head, Thomas Howard, Teesdale Iron Works, Stockton-on-Tees.
1853. Headly, James Ind, Eagle Works, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1862. Heath, William J. W., Colombo, Ceylon: (or care of John J. Heath, 105 Vyse Street, Birmingham.)
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1858. Hedley, John, Houghton-le-Spring, near Fence Houses.
1848. Hewitson, William Watson, Airedale Foundry, Leeds.
1862. Hingley, Samuel, Hart's Hill Iron Works, near Brierley Hill.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesborough.
1856. Hopkinson, John, Messrs. Wren and Hopkinson, Altrincham Street, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.

1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1858. Horsley, William, Jun., Hartley Engine Works, Seaton Sluice, near North Shields.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1860. Howard, James, Britannia Iron Works, Bedford.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1847. Howell, Joseph, Hawarden Iron Works, Holywell.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1862. Huber, Peter Emile, Vogelhutte, Zurich.
1861. Huffam, Frederick Thomas, Messrs. Slaughter Gruning and Co., Avonside Iron Works, Bristol.
1857. Humber, William, 20 Abingdon Street, Westminster, S.W.
1847. Humphrys, Edward, Deptford Pier, London, S.E.
1859. Hunt, James P., Corngreaves Iron Works, Corngreaves, near Birmingham.
1856. Hunt, Thomas, Tudela and Bilboa Railway, Bilboa: (or care of James Hunt, Crewe.)
1862. Hunter, Michael, Jun., Talbot Works, Johnson Street, Sheffield.
1860. Hurry, Henry C., Engineer, West Midland Railway, Worcester.

1857. Inshaw, John, Engine Works, Morville Street, Birmingham.

1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel Works, Sheffield.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 28A Broadwall, Stamford Street, Lambeth, London, S.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Sydney, Park Steel Works, Sheffield.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1847. Jobson, Robert, Dudley.
1847. Johnson, James, Great Northern Railway, Locomotive Department, Peterborough.
1848. Johnson, Richard William, Oldbury Carriage Works, near Birmingham.
1861. Johnson, Samuel Waite, Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1849. Johnson, William, 166 Buchanan Street, Glasgow.
1855. Johnson, William Beckett, Woodland's Bank, Altrincham, near Manchester.

1861. Jones, Alfred, Herbert's Park Iron Works, Bilston.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, Old Park Iron Works, Wednesbury.
1857. Jones, John Hodgson, 26 Great George Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesborough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near North Shields.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1848. Kirkham, John, 109 Euston Road, London, N.W.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1862. Knott, Joseph, Pennington Cotton Mill, Leigh, near Manchester.

1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 38 Waterloo Street, Birmingham.
1862. Lee, J. C. Frank, 30 Parliament Street, Westminster, S.W.
1860. Lee, John, Victoria Foundry, Litchurch, near Derby.
1857. Lees, Sylvester, Locomotive Superintendent, East Lancashire Railway, Bury, Lancashire.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1856. Linn, Alexander Grainger, Lynn.
1857. Little, Charles, Beehive Mills, Thornton Road, Bradford, Yorkshire.
1862. Lloyd, John, Lilleshall Iron Works, near Wellington, Shropshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Old Park Iron Works, Wednesbury.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, New Brown Street, Market Street, Manchester.
1859. Lord, Thomas Wilks, 2A Alfred Street, Boar Lane, Leeds.

1861. Low, George, Millgate Iron Works, Newark.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1856. Mackay, John, Mount Hermon, Drogheda.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Midland Railway, Derby.
1848. Marshall, Edwin, Britannia Carriage Works, Birmingham.
1862. Marshall, James, Engineer, Seaton Delaval Colliery, near Newcastle-on-Tyne.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Stourbridge Water Works, Stourbridge.
1860. Marten, George Priestley, Messrs. Stothert and Marten, Steam Ship Works, Bristol.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1857. Masselin, Armand, 16 Rue Dauphine, Paris.
1853. Mathews, William, Corbyn's Hall Iron Works, near Dudley.
1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1860. Mayer, Joseph, Iron Ship Builder, Linz, Austria: (or care of William Seyd, 35 Ely Place, Holborn, London, E.C.)
1859. Maylor, William, East Indian Iron Company, Beypoor: (or care of E. J. Burgess, 8 Austin Friars, London, E.C.)
1847. McClean, John Robinson, 17 Great George Street, Westminster, S.W.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Vulcan Iron Works, Worcester.
1862. McPherson, Hugh, Engineer, Gloucester Gas Works, Gloucester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1862. Miers, Francis C., Bohemia House, Chiswick, London, W.
1853. Miller, George Mackey, Great Southern and Western Railway, Dublin.
1862. Millward, John, Union Chambers, High Street, Stourbridge.

1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. Mitchell, James, Melrose Cottage, Plumstead Common, near Woolwich, S.E.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1857. Muntz, George Frederick, French Walls, near Birmingham.
1856. Muntz, George Henri Marc, Albion Tube Works, Nile Street, Birmingham.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.

1848. Napier, John, Vulcan Foundry, Glasgow.
1856. Napier, Robert, Vulcan Foundry, Glasgow.
1861. Natorp, Gustavus, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Locomotive Superintendent, East Indian Railway, Allahabad: (or care of Anthony Nichol, 22 Quay, Newcastle-on-Tyne.)
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1860. Oastler, William, Engineer, Worcester Gas Works, Worcester.
1847. Owen, William, Messrs. Sandford and Owen, Phœnix Works, Rotherham.

1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton, near Manchester.
1848. Pearson, John, 1 Manchester Buildings, Old Hall Street, Liverpool.
1859. Peet, Henry, London and North Western Railway, Locomotive Department, Wolverton.
1861. Perkins, Loftus, 6 Francis Street, Regent's Square, London, W.C.
1856. Perring, John Shae, 104 King Street, Manchester.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., Eccleston Hall, near Prescot.
1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.

1859. Platt, John, Hartford Iron Works, Oldham.
1862. Player, John, Norton, near Stockton-on-Tees.
1861. Plum, Thomas William, 69 King William Street, London, E.C.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, West Midland Railway, Worcester.
1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1862. Rake, Alfred Stansfield, Canal Street Works, Manchester.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 39 Wilton Crescent, Belgrave Square, London, S.W.
1862. Reynolds, Edward, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1862. Richardson, Robert, 26 Great George Street, Westminster, S.W.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1848. Robertson, Henry, Shrewsbury and Chester Railway, Shrewsbury.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1852. Rofe, Henry, Engineer, Birmingham Water Works, Paradise Street, Birmingham.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.
1857. Routledge, William, New Bridge Foundry, Salford, Manchester.
1860. Rumble, Thomas William, 6 Broad Street Buildings, New Broad Street, London, E.C.
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1848. Samuel, James, 26 Great George Street, Westminster, S.W
1857. Samuelson, Alexander, 28 Cornhill, London, E.C.
1857. Samuelson, Martin, Scott Street Foundry, Hull.
1861. Sanderson, George G., Parkgate Iron Works, Rotherham.
1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1858. Scott, Joseph, Messrs. R. & W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1848. Scott, Michael, 26 Parliament Street, Westminster, S.W.
1861. Scott, Walter Henry, London and North Western Railway, Locomotive Department, Crewe.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1862. Siemens, Frederick, 18 Beaufort Road, Edgbaston, Birmingham.
1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.
1862. Simpson, William, Conservative Club, St. James' Street, London, S.W.
1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, Atherstone.
1859. Slater, Isaac, Gloucester Wagon Company, Gloucester.
1853. Slaughter, Edward, Avonside Iron Works, Bristol.
1859. Smith, Charles Frederic Stuart, Mining Engineer, Midland Road, Derby.
1854. Smith, George, Wellington Road, Dudley.
1847. Smith, Henry, Spring Hill Works, Birmingham.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1859. Smith, Matthew, Fazeley Street Wire Mills, Birmingham.
1860. Smith, Richard, The Priory, Dudley.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1857. Snowdon, Thomas, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1859. Spencer, John Frederick, 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1853. Spencer, Thomas, Old Park Works, near Shiffnal.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1857. Stokes, Lingard, The White House, Newent, near Gloucester.

1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Allahabad.

1861. Sumner, William, 21 Clarence Street, Manchester.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley.

1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.

1859. Tannett, Thomas, Victoria Foundry, Leeds.

1861. Taylor, George, Clarence Iron Works, Leeds.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Jun., Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1857. Thompson, John Taylor, Messrs. R. and W. Hawthorn, Forth Banks, Newcastle-on-Tyne.

1857. Thompson, Robert, Haigh Foundry, near Wigan.

1862. Thompson, William, Spring Garden Engine Works, Newcastle-on-Tyne.

1852. Thomson, George, Crookhay Iron Works, Westbromwich.

1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1862. Tijou, William, St. Nicholas Works, Thetford.

1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)

1862. Tolmé, Julian Horn, 13 Duke Street, Westminster, S.W.

1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.

1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.

1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.

1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.

1856. Truss, Thomas, Shrewsbury and Chester Railway, Carriage Department, Chester.

1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.

1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Company, 146 Goswell Street, London, E.C.

1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. Mitchell, James, Melrose Cottage, Plumstead Common, near Woolwich, S.E.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1857. Muntz, George Frederick, French Walls, near Birmingham.
1856. Muntz, George Henri Marc, Albion Tube Works, Nile Street, Birmingham.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.

1848. Napier, John, Vulcan Foundry, Glasgow.
1856. Napier, Robert, Vulcan Foundry, Glasgow.
1861. Natorp, Gustavus, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Locomotive Superintendent, East Indian Railway, Allahabad: (or care of Anthony Nichol, 22 Quay, Newcastle-on-Tyne.)
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1860. Oastler, William, Engineer, Worcester Gas Works, Worcester.
1847. Owen, William, Messrs. Sandford and Owen, Phœnix Works, Rotherham.

1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton, near Manchester.
1848. Pearson, John, 1 Manchester Buildings, Old Hall Street, Liverpool.
1859. Peet, Henry, London and North Western Railway, Locomotive Department, Wolverton.
1861. Perkins, Loftus, 6 Francis Street, Regent's Square, London, W.C.
1856. Perring, John Shae, 104 King Street, Manchester.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., Eccleston Hall, near Prescot.
1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.

1859. Platt, John, Hartford Iron Works, Oldham.
1862. Player, John, Norton, near Stockton-on-Tees.
1861. Plum, Thomas William, 69 King William Street, London, E.C.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, West Midland Railway, Worcester.
1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1862. Rake, Alfred Stansfield, Canal Street Works, Manchester.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 39 Wilton Crescent, Belgrave Square, London, S.W.
1862. Reynolds, Edward, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1862. Richardson, Robert, 26 Great George Street, Westminster, S.W.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1848. Robertson, Henry, Shrewsbury and Chester Railway, Shrewsbury.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1852. Rofe, Henry, Engineer, Birmingham Water Works, Paradise Street, Birmingham.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.
1857. Routledge, William, New Bridge Foundry, Salford, Manchester.
1860. Rumble, Thomas William, 6 Broad Street Buildings, New Broad Street, London, E.C.
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1848. Samuel, James, 26 Great George Street, Westminster, S.W
1857. Samuelson, Alexander, 28 Cornhill, London, E.C.
1857. Samuelson, Martin, Scott Street Foundry, Hull.
1861. Sanderson, George G., Parkgate Iron Works, Rotherham.
1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1857. Armstrong, Joseph, Great Western Railway, Locomotive Department, Wolverhampton.

1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.

1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.

1848. Ashbury, John, Openshaw Works, near Manchester.

1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1848. Bagnall, William, Gold's Hill Iron Works, Westbromwich.

1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.

1848. Baker, William, London and North Western Railway, Euston Station, London, N.W.

1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.

1860. Barker, Paul, Old Park Iron Works, Wednesbury.

1862. Barrow, Joseph, Wellington Foundry, Leeds.

1862. Barton, Edward, Rutland Steel Works, Sheffield.

1847. Barwell, William Harrison, Eagle Foundry, Northampton.

1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.

1860. Batho, William Fothergill, Bordesley Works, Birmingham.

1859. Beacock, Robert, Victoria Foundry, Leeds.

1860. Beale, William Phipson, Parkgate Iron Works, Rotherham.

1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.

1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.

1860. Beck, Richard, Lister Works, Upper Holloway, London, N.

1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.

1858. Bell, Isaac Lothian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.

1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.

1854. Bennett, Peter Duckworth, Spon Lane Iron Works, Westbromwich.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton, near Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.

1851. Blackwell, Samuel Holden, Russell's Hall Iron Works, near Dudley.

1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1847. Bovill, George Hinton, Durnsford Lodge, Wandsworth, Surrey, S.W.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.
1862. Boyd, Nelson, Mining Engineer, Hartington, near Ashbourne.
1854. Bragge, William, Atlas Steel Works, Sheffield.
1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.
1856. Bray, Edwin, Nevill Holt, near Market Harborough.
1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel Works, Sheffield.
1855. Brown, John, Mining Engineer, Barnsley.
1856. Brown, John, Mining Engineer, Bank Top, Darlington.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1858. Burn, Henry, Midland Railway, Locomotive Department, Sheffield.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.
1859. Butler, John, Old Foundry, Stanningley, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Midland Great Western Railway, Dublin
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel Works, Sheffield.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Carpmael, William, 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1849. Chamberlain, Humphrey, 3 St. John's, Wakefield.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1847. Clift, John Edward, Durnford Place, Coventry Road, Birmingham.
1860. Clunes, Thomas, Vulcan Iron Works, Worcester.
1847. Cochrane, Alexander Brodie, Woodside Iron Works, near Dudley.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesborough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1847. Coke, Richard George, Mining Engineer, 6 Market Hall Chambers, Chesterfield.

We earnestly pray that your Majesty and your Royal Family may be supported in this great affliction by the consciousness of the entire devotion and sympathy of all your subjects; and that your Majesty's life may be prolonged for many years in health and happiness, to reign over a faithful and affectionate people.

For the Institution of Mechanical Engineers,

W. G. Armstrong,

President.

The Minutes of the last General Meeting were read and confirmed. The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1862.

The Council have much pleasure, on this the Fifteenth Anniversary of the Institution, in congratulating the Members on the very satisfactory progress and prosperous condition of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1861, shows a balance in the Treasurer's hands of £1420 9*s.* 5*d.* after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1861, and report that the following balance sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the past year; the total number of Members of all classes for the year being 464, of whom 18 are Honorary Members, and 3 are Graduates.

The following deceases of Members of the Institution have occurred during the past year 1861:—

William D. Burlinson,	Sunderland.
John Horridge Deane,	Liverpool.
Eaton Hodgkinson,	Manchester.
John Lees,	Ashton-under-Lyne.
John Ross,	Birmingham.
Thomas John Taylor,	Newcastle-on-Tyne.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year, and expressing their thanks to the donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present to the Institution copies of their works.

LIST OF DONATIONS TO THE LIBRARY.

Report of the Committee on the Construction of Submarine Cables; from Capt. Galton, R.E.

Fourth Report of the Commissioner on the Internal Communications of New South Wales; from Capt. Martindale, R.E.

Statistical Register of New South Wales; from Capt. Martindale, R.E.

Treatise on the Steam Engine, by John Bourne; from Mr. James Kennedy.

Mills and Millwork, by William Fairbairn; from the author.

Iron, its History and Manufacture, by William Fairbairn; from the author.

Report of the Commissioner of Patents, United States, 1859.

The Channel Railway, by James Chalmers; from the author.

Report of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Proceedings of the Royal Institution of Great Britain, from the commencement; from the Institution.

Proceedings of the Institution of Civil Engineers; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Journal of the Royal United Service Institution; from the Institution.

Transactions of the Institution of Engineers in Scotland; from the Institution.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Transactions of the Royal Scottish Society of Arts; from the Society.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Journal of the Society of Arts; from the Society.
The Engineer; from the Editor.
The Mechanics' Magazine; from the Editor.
The Civil Engineer and Architect's Journal; from the Editor.
The London Journal of Arts; from the Editor.
The Artizan Journal; from the Editor.
The Practical Mechanic's Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Steam Shipping Journal; from the Editor.
Photographs of Steam Engines; from Mr. T. H. Murray.

The Council have great satisfaction in referring to the number of Papers that have been brought before the meetings during the past year, and the practical value and interest of many of the communications, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the meetings during the last year:—

Address of the President, Sir William G. Armstrong.

Description of the Buda Wrought Iron Lighthouse; by Mr. John H. Porter, of Birmingham.

On Benson's High Pressure Steam Boiler; by Mr. John James Russell, of Wednesbury.

Description of a method of Supplying Water to Locomotive Tenders whilst running; by Mr. John Ramsbottom, of Crewe.

Description of a Self-acting Machine for Spooling Thread; by Mr. William Weild, of Manchester.

On a new mode of Coking in Ovens, applied to the Staffordshire Slack; by Mr. Alexander B. Cochrane, of Dudley.

On a Boiler, Engine, and Surface Condenser, for very high pressure steam with great expansion; by Alexander W. Williamson, Ph.D., and Mr. Loftus Perkins, of London.

On the Manufacture of Steel Rails and Armour Plates; by Mr. John Brown, of Sheffield.

On the Manufacture of Cast Steel and its Application to constructive purposes; by Mr. Henry Bessemer, of London.

On the Strength of Steel containing different proportions of Carbon; by Mr. T. Edward Vickers, of Sheffield.

On the Construction and Erection of Iron Piers and Superstructures for Railway Bridges in alluvial districts; by Lt.-Colonel J. P. Kennedy, of London.

On Cast Iron Tubbing used in sinking shafts; by Mr. John Brown, of Barnsley.

Description of a Rivet-Making Machine; by Mr. Charles De Bergue, of Manchester.

On an application of Giffard's Injector as an Elevator for the Drainage of colliery workings; by Mr. Charles W. Wardle, of Leeds.

Description of Sellers' Screwing Machine; by Mr. Charles P. Stewart, of Manchester.

The Council have particular pleasure in referring to the great success and interest of the Meeting of the Institution in Sheffield last summer, and in expressing their special thanks to the Local Committee and the Honorary Local Secretary, Mr. T. F. Cashin, for the excellent reception that was given to the Members of the Institution on that occasion; and they look forward with much confidence to the important advantages arising from the continuance of these Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts of the country, and the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, will go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present annual meeting for the election of the Officers and Council for the ensuing year.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31st December, 1861.

Cr.	£	s.	d.
By Balance 31st December, 1860	1109	2	11
,, Subscriptions from 24 Members in arrear	72	0	0
,, ditto from 389 Members for 1861	1167	0	0
,, ditto from 3 Graduates for 1861	6	0	0
,, ditto from 3 Members in advance for 1862	9	0	0
,, Entrance Fees from 49 New Members	98	0	0
,, ditto from 1 New Graduate	1	0	0
,, Sale of Extra Reports	4	8	0
,, Interest from Bank	34	3	0
	£2500	18	11

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	368	11	0			
Less Authors' copies of papers, repaid	18	19	0	349	12	0
,, Stationery and Printing				49	7	10
,, Office Expenses and Petty Disbursements				36	5	2
,, Expenses of Meetings				21	5	6
,, Fittings and Repairs				3	17	2
,, Travelling Expenses				12	10	5
,, Parcels				2	17	8
,, Postages				39	16	3
,, Salaries				450	0	0
,, Rent and Taxes				114	12	6
,, Balance 31st December, 1861				1420	9	5
				£2500	18	11

(Signed) SAMPSON LLOYD, WALTER MAY, } Finance Committee.

30th January, 1862.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—incrustation of boilers, and means of prevention—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves, bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double-cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm-governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—use of coal—consumption of smoke—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by Gas, or explosive compounds—Electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of the application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax and other fibrous materials, both in the natural length of staple and when cut.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

LATHES, PLANING, BORING, DRILLING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto

FIRE ENGINES, hand and steam, ditto ditto ditto

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto

CRANES, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction and results of working.

COFFER DAMS AND PILING, facts relating to the construction—cast iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto

PILE DRIVING APPARATUS, particulars of improvements—use of steam power —particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast iron and wrought iron, ditto ditto

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, consumption of fuel in different kinds—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working

of hot blast ovens—pyrometers—means and results of application of waste gas from close-topped and open-topped furnaces.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS and FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking—mixtures of coal slack and other materials—evaporative power of different varieties.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of solid wrought iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

The communications should be written on foolscap paper, on one side only of each page, leaving a clear margin on the left side for binding, and they should be written in the third person. The drawings illustrating the paper should be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper; or enlarged diagrams should be added for the illustration of any particular portions: the scale of each drawing to be marked upon it.

MEMOIRS

OF MEMBERS DECEASED IN 1861.

WILLIAM DAVIE BURLINSON was born at Durham in 1802; and after serving his time with Messrs. John Burlinson and Co., engineers and millwrights, Sunderland, became a member of the firm in 1830, in which he took an active part. He erected machinery for the shipment of coals at several sea ports, his father having been the inventor of this description of machinery; and he gave great attention to the manufacture of machinery for making hemp and wire ropes, including the machines for making the Atlantic submarine telegraph cable. His health had been declining for upwards of three years previous to his death, which took place on 4 September 1861, at the age of fifty-nine. He was elected a Member of the Institution in 1858.

JOHN HORRIDGE DEANE was born at Liverpool in 1828, and after serving his time with Messrs. Bury Curtis and Kennedy of that town was appointed in 1854 locomotive superintendent of the Barcelona and Granollers Railway in Spain, and afterwards general manager of the line, until 1859, when he received an engineering appointment in Russia; but he was obliged to return home early in 1860 in consequence of declining health, and died on 10 August 1861 at the early age of thirty-three, after an illness of 18 months. He was elected a Member of the Institution in 1857.

EATON HODGKINSON was born in February 1789 at Anderton near Northwich, Cheshire, where he received his first education at the grammar school. He was originally intended for the church; but his father having died when he was only six years old, he commenced his career as a farmer, to aid his widowed mother in carrying on his

father's business. Neither farming nor the church were however suited to his talents, and at the age of twenty-one he removed with his mother to Salford, Manchester, where they maintained themselves by keeping a shop, whilst he had the advantages of scientific instruction and society, and devoted his spare hours to the study of mathematics and mechanical science, as one of Dr. Dalton's private pupils. At the age of thirty-three, he produced his first scientific work, an essay on the Transverse Strain and Strength of Materials, which was followed by a series of papers on the subject of Suspension Bridges read by him to the Manchester Philosophical Society in 1828 to 1830, his attention having been called to this subject by the erection and failure of a suspension bridge at Broughton near Manchester. In 1833 he commenced that remarkable series of papers and researches on the strength and strains of materials, more especially of Iron, by which he became so eminently distinguished and made so important an addition to the scientific knowledge at the disposal of engineers. In these researches he seems only to have resumed the subject of his earliest paper in 1822, which he may be considered to have completed when in 1857 he received the medal of the Royal Society and in 1861 became Vice-President of the British Association.

The great subject that Eaton Hodgkinson devoted himself to—the investigation of the nature and properties of iron—he followed up with an assiduity of research, a philosophical method, and a clear and strong sagacity, that enabled him to accomplish results which have been of the greatest practical importance in the various and extensive applications of iron, and have effected a complete revolution in practice with that metal, laying all branches of engineering under a great debt of gratitude to him. Before his investigations the mechanical nature and the relative value of cast iron and wrought iron were little understood; and neither the practical value of their resistance to strains, nor the true form and distribution of material for obtaining the best application of their strength to mechanical use, were known: wrought iron was not trusted or used so much as it deserved, whilst cast iron was unduly relied on and inefficiently applied. The section of cast iron girders previously in universal use was an I shape, with nearly equal flanges at top and bottom; but

Hodgkinson showed that the resistance of cast iron to fracture by compression being about five times its resistance to tension, the upper flange acting by compression should have only one fifth of the area of the bottom flange in tension, in order to be equal in strength and give the maximum strength of girder with the minimum weight of material, the section of the girder being therefore somewhat of a ⊥ shape: a great saving in the weight of material required was thereby effected. He showed also the true action of the vertical web of the girder in preserving the top and bottom flanges in their relative positions, and ascertained the extent to which its thickness should be diminished, whereby the weight of material was still further reduced.

In the form and calculation of cast iron columns Eaton Hodgkinson also established some remarkable facts by a series of experiments on the force necessary to crush the column, which he found to be regular: he proved that the bearing strength was increased by enlarging the column in the middle, and also by making the ends flat instead of rounded; while it was diminished by adding to the height of the column beyond a certain point. His formulæ for the calculation of solid and hollow columns, deduced from these experiments, have become the standards in general use. In his investigation of the best form and proportions for wrought iron columns and beams, he showed how the inferior resistance to compression of wrought iron as compared with cast iron could be compensated for by correct distribution of the material, removing the previous practical objections to wrought iron for large structures, and leading to the gradual displacement of cast iron by the more safe and reliable material, wrought iron, thereby affording facilities for overcoming engineering difficulties previously almost insurmountable. He was also engaged in important investigations into the application of iron to railway structures, and the relative values of hot and cold-blast iron, in connexion with a Royal Commission and a committee of the British Association.

Eaton Hodgkinson was eminently a self-made and self-educated man. Deprived in early life of the benefits of a complete education, he devoted himself earnestly to business for the support of his family, and afterwards for the purchase of an honourable leisure, which he

employed first in the completion of his own education, next in association with eminent men of science in Manchester, and finally in the advancement of mechanical science and public researches into various important branches of the subject. From his humble origin he raised himself by his exertions and talents to be successively Member of the Philosophical Society of Manchester, Fellow of the Royal Society, Vice-President of the British Association, and Professor in University College, London: a bright example that the humblest occupation need not derogate from the dignity of personal character, nor interfere with the accomplishment of a brilliant career of public usefulness and high distinction. The secret of his success was undoubtedly his earnestness and singleness of purpose; whatever investigation he undertook he determined to get thoroughly to the bottom of the subject; and held that to understand part of a subject completely, it was requisite to master the whole. He was elected an Honorary Life Member of this Institution in 1849, and died on 18 June 1861 at the age of seventy-two.

John Lees was born at Park Bridge in 1827, and as the active member for ten years in the firm of Messrs. H. Lees and Sons, of Park Bridge Iron Works, Ashton-under-Lyne, was engaged principally in roller making for the use of the cotton spinning districts, in which he introduced several improvements in machines for the manufacture of rollers, &c. He became a Member of the Institution in 1857, and died on 8 October 1861, after a short illness, at the age of thirty-four.

John Ross was born at Perth in 1812, his father being a stone mason; he was apprenticed to a coach maker at Perth, and subsequently worked at Edinburgh. In 1845 he became foreman to Mr. Thomas Brown, carriage builder, at Birmingham, in whose works he had been for about two years previously; and in 1846 he became manager at Messrs. Brown Marshalls and Co.'s Railway Carriage Works at Birmingham. He was a Member of the Institution from 1853 to the time of his death, which occurred on 22 January 1861, in the forty-ninth year of his age.

Thomas John Taylor, of Earsdon near Newcastle-on-Tyne, was born in 1810 at Shilbottle near Alnwick, and after receiving a liberal education, which he finished at the university of Edinburgh, was brought up under his uncle, Mr. Hugh Taylor, as a colliery viewer, having the care first of some smaller collieries, and afterwards of Haswell Colliery in the county of Durham, a colliery of great extent and importance. He subsequently succeeded his uncle as mining engineer to the Duke of Northumberland, and acted in the same capacity also for the collieries of Lord Hastings and Col. Towneley. He attained a position of great eminence as a mining engineer, and wrote frequently upon subjects connected with mining and the coal trade. In 1843 he published an historical account of coal mining as practised in the North of England, and in 1859 read a paper at this Institution on the progressive application of machinery to mining purposes, having been elected a Member of the Institution in 1858: his principal work was a treatise on the improvement of the river Tyne, as a great shipping port for coal, giving his views also on the improvement and management of rivers and tidal harbours generally. The last mining project on which he was occupied at the time of his death was the organisation of a comprehensive system for the combined drainage of the whole coal basin of the Tyne, east of Newcastle. His death occurred on 2 April 1861, in the fifty-first year of his age, after a very short illness originating in a violent cold.

The CHAIRMAN remarked that the successful position of the Institution shown by the Report of the Council was highly gratifying and encouraging, and he moved that the Report be received and adopted, which was passed. He announced that the Annual Special Meeting of the Institution would be held in London in the ensuing summer, when they would no doubt have the presence of many engineers from the continent who would be in London on the occasion of the International Exhibition; and he hoped all the Members would do their best to render the meeting thoroughly successful.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were duly elected for the ensuing year:—

PRESIDENT.

SIR WILLIAM G. ARMSTRONG,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

ALEXANDER B. COCHRANE,	Dudley.
JAMES FENTON,	Low Moor.
HENRY MAUDSLAY,	London.
JOHN PENN,	London.
JOHN RAMSBOTTOM,	Crewe.
JOSEPH WHITWORTH,	Manchester.

COUNCIL.

ALEXANDER ALLAN,	Perth.
GEORGE HARRISON,	Birkenhead.
THOMAS HAWKSLEY,	London.
EDWARD JONES,	Wednesbury.
CHARLES P. STEWART,	Manchester.

Members of Council remaining in office.

JOHN ANDERSON,	Woolwich.
CHARLES F. BEYER,	Manchester.
EDWARD A. COWPER,	London.
JOHN FERNIE,	Derby.
ROBERT HAWTHORN,	Newcastle-on-Tyne.
JAMES KITSON,	Leeds.
SAMPSON LLOYD,	Wednesbury.
WALTER MAY,	Birmingham.

C. William Siemens, . . .	London.
William Weallens, . .	Newcastle-on-Tyne.

TREASURER.

Henry Edmunds, . . .	Birmingham.

SECRETARY.

William P. Marshall, . .	Birmingham.

The following New Members were also elected :—

MEMBERS.

William Deakin, . . .	Willenhall.
John Elder, ...	Glasgow.
Michael Hunter, Jun., . .	Sheffield.
John Loxton, . . .	Bilston.
James Marshall, . . .	Seaton Delaval.
John Player, . . .	Stockton-on-Tees.
Robert James Ransome, . .	Ipswich.
William John Sharpe, . .	London.
Frederick Siemens, . . .	London.
William Stableford, . .	Oldbury.
William Tijou, ...	London.
William Edward Winby, .	London.

The following paper was then read :—

ON A REGENERATIVE GAS FURNACE, AS APPLIED TO GLASSHOUSES, PUDDLING, HEATING, ETC.

By Mr. C. WILLIAM SIEMENS, of London.

The arrangement of furnaces about to be described is applicable with the greatest advantage in cases where great heat has to be maintained: as in melting and refining glass, steel, and metallic ores, in puddling and welding iron, and in heating gas and zinc retorts, &c. The fuel employed, which may be of very inferior description, is separately converted into a crude gas, which in being conducted to the furnace has its naturally low heating power greatly increased by being heated to nearly the high temperature of the furnace itself, ranging to above 3000° Fahr.; undergoing at the same time certain chemical changes whereby the heat developed in its subsequent combustion is increased. The heating effect produced is still further augmented by the air necessary for combustion being also heated separately to the same high degree of temperature, before mixing with the heated gas in the combustion chamber or furnace; and the latter is thus filled with a pure and gentle flame of equal intensity throughout the whole chamber. The heat imparted to the gas and air before mixing is obtained from the products of combustion, which after leaving the furnace are reduced to a temperature frequently not exceeding 250° Fahr. on reaching the chimney, whereby great economy in fuel is produced, with other advantages.

The transfer of heat from the products of combustion to the air and gas entering the furnace is effected by means of Regenerators, the principle of which has been recognised to some extent since the early part of the present century, but has not hitherto been carried out in any useful application in the arts, unless the respirator invented by Dr. Jeffreys be so considered. The discovery of this principle is

ascribed to Rev. Mr. Stirling of Dundee, who in conjunction with his brother, James Stirling, attempted as early as the year 1817 to apply it to the construction of a hot air engine: their engine did not however succeed, nor did Capt. Ericsson's later attempts in the same direction lead to more satisfactory results. The economical principle of the regenerator having attracted the writer's attention in 1846, he constructed in the following year an engine in which superheated steam was used in conjunction with the regenerator: many practical difficulties however prevented a realisation of the success which theory and experiments appeared to promise; but it is gratifying to find that one principle then adopted, that of superheating the steam, has since received the sanction of an extended application.

The employment of regenerators for getting up a high degree of heat in furnaces was suggested in 1857 by the writer's brother, Mr. Frederick Siemens, and has since been worked out by them conjointly through the several stages of progressive improvement. The results obtained by the earlier applications of the principle were communicated by the writer in a paper read at a former meeting of this Institution (see Proceedings Inst. M.E., 1857, page 103): and two or three of the furnaces then described, employed for heating bars of steel, remain still in operation. In attempting however to apply the principle to puddling and other larger furnaces, serious practical difficulties arose, which for a considerable time frustrated all efforts; until by adopting the plan of volatilising the solid fuel in the first instance, and employing it entirely in a gaseous form for heating purposes, practical results were at length attained surpassing even the sanguine expectations previously formed.

In the early form of the regenerative heating furnace, which has been in continuous work during the last three years for heating bars of steel at Messrs. Marriott and Atkinson's Steel Works, Sheffield, and also at the Broughton Copper Works, Manchester, there is a single fireplace containing a ridge of fuel fed from the top; and two heating chambers, in which the bars of metal to be heated are laid, with a regenerator at the end of each chamber, by which the waste heat passing off from the furnace is intercepted on its way to the

chimney, and transferred to the air entering the furnace. Each regenerator is composed of a mass of open firebricks, exposing a large surface for the absorption of heat, through which the products of combustion are made to pass from the furnace, and are thus gradually deprived of nearly all their heat previous to escaping into the chimney: the end of the regenerator nearest the furnace becomes gradually heated to nearly the temperature of the furnace itself, while the other end next the chimney remains comparatively cool. The direction of the draught being now reversed by means of a valve, the air entering the furnace is made to pass through the heated regenerator in the contrary direction, encountering first the cooler portions of the brickwork, and acquiring successive additions of heat in passing through the regenerator, until it issues into the first chamber of the furnace at a very high temperature, and traversing the ridge of fuel produces a flame which fills the second heating chamber; whence the products of combustion passing through the second cold regenerator deposit their heat successively in the inverse manner, reaching the chimney comparatively cool. By thus alternating the current through the two regenerators, a high degree of temperature is maintained constantly in the furnace. This arrangement of furnace is evidently applicable only in exceptional cases where two chambers are to be heated alternately, nor does it admit of being carried out upon a large scale.

In heating a single chamber the expedient was resorted to of providing two fireplaces to be traversed in succession by the heated air, with the heating chamber placed between, as in the furnace shown in the drawings accompanying the previous paper (Proceedings Inst. M. E., 1857, Plate 118). Here the difficulty arose that the air, the oxygen of which was already combined with carbon (forming carbonic acid) in traversing the first fireplace, took up a second equivalent of carbon (forming carbonic oxide) in traversing the second, so that the fuel of the second fire was consumed to no purpose. In order to diminish this loss and also avoid impairing the draught by a double resistance, the ridges of fuel were discontinued and the coal was fed into the furnace from the sides, resting on a solid hearth, to be there volatilised by the heated air passing over it. By frequently stirring the

first fire its combustion was favoured until the current was reversed, when it was left undisturbed until the next change, and so on alternately. It was found very difficult however to maintain an active and uniform combustion and to burn the purely carbonaceous substance that was left in the fireplace after the gaseous portion of the fuel had been volatilised; and it had frequently to be raked out in order to make room for fresh gaseous fuel. This circumstance led to the first step towards the employment of fuel in the form of gas, by providing a small grate below the heap of fuel, through which a gentle current of air was allowed to enter, forming carbonic oxide, which afterwards further combined with oxygen on meeting with the hot current of air entering the furnace from the regenerator. The two fireplaces of alternating activity were however attended with considerable practical inconvenience: the furnacemen in particular disliked the idea of attending two fireplaces instead of one, and being little interested in the saving of fuel, took no pains to work the furnace in a satisfactory manner.

It therefore became necessary to devise a plan of heating a single chamber continuously by one fireplace, in combination with the alternate reversal of currents through the regenerators, but without reversing the direction of the flame. This was accomplished by means of double reversing valves, and was practically carried out in a puddling furnace that worked for a considerable length of time at the ironworks of Messrs. R. and W. Johnson near Manchester. The two regenerators were placed longitudinally side by side, with a flue between, underneath the puddling chamber, and the fireplace was put at one end of the puddling chamber, as in an ordinary puddling furnace, and fed with fuel from above. The heated air from the first regenerator was brought up at the back of the fireplace, and meeting there with the fuel produced the required flame in the puddling chamber; whence the products of combustion passed down at the end of the chamber, and were carried back along the flue below to the hot end of the second regenerator, through which they made their way to the chimney. For reversing the currents through the regenerators two valves were needed, connected by a lever, one at the hot end of the regenerators near the fire, and the other at the cool end next the chimney; whereby the

heated air was made to enter the fireplace by the same passage as previously, and the direction of the flame through the puddling chamber was not changed. By this arrangement the regenerative furnace was assimilated as nearly as could be to an ordinary puddling furnace in form and mode of working. The few furnaces constructed in this manner produced a great heat with little more than one half the consumption of fuel of ordinary furnaces in doing the same amount of work. A considerable saving of iron was also effected in puddling, owing to the absence of strong cutting draughts, a mild draught being found sufficient to produce the necessary heat. There still remained drawbacks however which prevented an extensive application of this form of furnace: the fire required frequent attention, and it was difficult to maintain a uniform volume of flame in the furnace; the reversing valve at the hot end of the regenerators was moreover liable to get out of order, and the furnace was costly to erect.

The most important step in the development of the regenerative furnace has been the complete separation of the fireplace or gas producer from the heating chamber or furnace itself. When a uniform and sufficient supply of combustible gas is ensured, it can evidently be heated just like the air, by being passed through a separate regenerator before reaching the furnace, whereby its heating power is greatly increased. The difficulty of maintaining a uniform flame in the furnace is thereby certainly removed, and there is no longer any necessity for keeping the flame always in the same direction through the furnace, since the gas can be introduced with equal facility at each end of the heating chamber in turn, and the periodical change of direction of the flame through the furnace tends only to make the heat more uniform throughout: whereas in the previous plan of employing solid fuel for heating in the furnace, the relative position of the fireplace and heating chamber being fixed and unchangeable required the direction of the flame to be kept always the same, unaltered by the reversal of currents through the regenerators. The new plan of a separate gas producer has now been successfully carried out in practice, and there are already a considerable number of the regenerative gas furnaces in satisfactory operation in this country and on the continent, applied to

glasshouses, iron furnaces, &c. In the neighbourhood of Birmingham, at Messrs. Lloyd and Summerfield's Glass Works, a flint glass furnace constructed upon this plan has now been in continuous operation for nearly twelve months, and affords a good opportunity for ascertaining the consumption of fuel of the regenerative furnace as compared with the previous furnace performing the same work. At the Glass Works of Messrs. Chance Brothers and Co. near Birmingham, the regenerative gas furnace has been under trial for the same length of time, and has latterly been adopted for the various purposes in crown and sheet glass making upon a very large scale. Messrs. James Russell and Sons, Crown Tube Works, Wednesbury, are also applying the furnace to the delicate operation of welding iron tubes, and in a short time will probably employ no solid fuel for any furnaces at their works. Another flint glass furnace erected by Messrs. Osler in Birmingham, and several puddling furnaces erected by Messrs. Gibbs Brothers at Deepfields, and by Mr. Richard Smith at the Round Oak Iron Works, are amongst the latest applications of the regenerative gas furnace, the designs having in all cases been furnished by the writer and carried out under his brother's immediate superintendence.

The Gas Producer is shown in Figs. 1, 2, and 3, Plates 1 and 2: Fig. 1 is a longitudinal section, Fig. 2 a front elevation and transverse section at the front, and Fig. 3 a transverse section at the back. The producers are entirely separate from the furnace where the heat is required, and are made sufficient in number and capacity to supply several furnaces. The fuel, which may be of the poorest description, such as slack, coke dust, lignite, or peat, is supplied at intervals of from 6 to 8 hours through the covered holes A, Figs. 1 and 2, and descends gradually on the inclined plane B, which is set at an inclination of from 45° to 60° according to the nature of the fuel used. The upper portion of the incline B is made solid, being formed of iron plates covered with firebrick; but the lower portion C is an open grate formed of horizontal flat steps. At the foot of the grate C is a covered water trough D, filled with water up to a constant level from the small feeding cistern E, supplied by a water pipe with a ball tap. The large opening under the water trough is convenient for drawing out clinkers, which generally collect at that point. The small stoppered

holes F F at the front and G G at the top of the producer are provided to allow of putting in an iron bar occasionally to break up the mass of fuel and detach clinkers from the side walls. Each producer is made large enough to hold about 10 tons of fuel in a low incandescent state, and is capable of converting about 2 tons of it daily into a combustible gas, which passes off through the opening H into the main gas flue leading to the furnaces.

The action of the gas producer in working is as follows: the fuel descending slowly on the solid portion B of the inclined plane, Plate 1, becomes heated and parts with its volatile constituents, the hydro-carbon gases, water, ammonia, and some carbonic acid, which are the same as would be evolved from it in a gas retort. There now remains from 60 to 70 per cent. of purely carbonaceous matter to be disposed of, which is accomplished by the slow current of air entering through the grate C, producing regular combustion immediately upon the grate; but the carbonic acid thereby produced, having to pass slowly on through a layer of incandescent fuel from 3 to 4 feet thick, takes up another equivalent of carbon, and the carbonic oxide thus formed passes off with the other combustible gases to the furnace. For every cubic foot of combustible carbonic oxide thus produced, taking the atmosphere to consist of 1-5th part by volume of oxygen and 4-5ths of nitrogen, two cubic feet of incombustible nitrogen pass also through the grate, tending greatly to diminish the richness or heating power of the gas. Not all the carbonaceous portion of the fuel is however volatilised on such disadvantageous terms: for the water trough D at the foot of the grate, absorbing the spare heat from the fire, emits steam through the small holes I under the lid; and each cubic foot of steam in traversing the layer of from 3 to 4 feet of incandescent fuel is decomposed into a mixture consisting of one cubic foot of hydrogen and nearly an equal volume of carbonic oxide, with a variable small proportion of carbonic acid. Thus one cubic foot of steam yields as much inflammable gas as five cubic feet of atmospheric air; but the one operation is dependent upon the other, inasmuch as the passage of air through the fire is attended with the generation of heat, whereas the production of the water gases, as well as the evolution of the hydro-carbons, is carried on at the expense of heat. The generation

of steam in the water trough being dependent on the amount of heat in the fire, regulates itself naturally to the requirements; and the total production of combustible gases varies with the admission of air. And since the admission of air into the grate depends in its turn upon the withdrawal of the gases evolved in the producer, the production of the gases is entirely regulated by the demand for them. The production of gas may even be arrested entirely for 12 hours without deranging the producer, which will begin work again as soon as the gas valve of the furnace is reopened; since the mass of fuel and brickwork retain sufficient heat to keep up a dull red heat in the producer during that interval. The gas is however of a more uniform quality when there is a continuous demand for it, and for this reason it is best to supply several furnaces from one set of producers, so as to keep the producers constantly at work. The opening H leading from each producer into the main gas flue can be closed by inserting a damper from above, as shown in Fig. 1, in case any one of the producers is required to be stopped for repairs or because part of the furnaces supplied are out of work.

It is important that the main gas flue leading to the furnaces should contain an excess of pressure however slight above the atmosphere, in order to prevent any inward draughts of air through crevices, which would produce a partial combustion of the gas and diminish its heating power in the furnace, besides causing a deposit of soot in the flues. It is therefore necessary to deliver the gas into the furnace without depending upon a chimney draught for that purpose. This could easily be accomplished if the gas producers were placed at a lower level than the furnaces, but as that is generally impossible, the following plan has been adopted. The mixture of gases on leaving the producers has a temperature ranging between 300° and 400° Fahr., which must under all circumstances be sacrificed, since it makes no difference to the result at what temperature the gas to be heated enters the regenerators, the final temperature being in all cases very nearly that of the heated chamber of the furnace or say 2500° Fahr. The initial heat of the gas is therefore made available for producing a plenum of pressure by making the gas rise about 20 feet above the producers, then carrying it horizontally 20 or 30 feet through the wrought iron tube J, Plate 1, and

letting it again descend to the furnace, as shown by the arrows in Fig. 1. The horizontal tube J being exposed to the atmosphere causes the gas to lose from 100° to 150° of temperature, which increases its density from 15 to 20 per cent. and gives a preponderating weight to that extent to the descending column, urging it forwards into the furnace.

The application of the regenerative gas furnace as a Plate Glass Melting Furnace is shown in Plates 3 to 6, which represent a melting furnace now in course of erection at the British Plate Glass Works near St. Helen's. This furnace does not differ materially from the regenerative gas furnaces previously erected and at work at Messrs. Chance's and Messrs. Lloyd and Summerfield's, but is selected in preference because it is the most improved in details of construction. Plate 3 shows a longitudinal section of the furnace, Plate 4 a transverse section, and Plate 5 a sectional plan above and below the bed or "siege" as it is termed of the furnace. Figs. 7, 8, and 9, Plate 6, show the detail of the gas and air valves.

The heating chamber A of the furnace, Figs. 4 and 5, contains twelve glass pots B, which are got out through the side doors when the glass is ready for casting upon the moulding table. Underneath are placed transversely the four regenerators C C, composed of open firebricks built up on a grating, which are arched over at the top and support the bed or siege D of the furnace. The regenerators work in pairs, the two under the right hand end of the siege communicating with that end of the heating chamber, while the other two communicate with the opposite end, as shown in Fig. 4. The gas enters the chamber through the three passages E, Figs. 5 and 6, and the air through the two intermediate passages F, whereby they are kept entirely separate up to the moment of entering the furnace, but are then able immediately to mingle intimately, producing at once an intense and uniform flame in the heating chamber. The siege D is built of firebrick, with a number of transverse channels, shown black in Figs. 4 and 8, through which the cold entering air is made to pass on its way into the air flue G, as shown by the arrows in Fig. 5; by this means the siege is kept comparatively cool, so that no fluid glass can pass through crevices into the regenerators. Any melted glass

that may fall from the heating chamber through the apertures at the ends of the siege does not get into the regenerators, but falls into the pockets M, Fig. 4, whence it can be removed through the opening at the bottom. The passage N, Fig. 5, by which the air enters, affords the means of getting at the regenerators through an opening at the end of each.

From the air flue G, Fig. 8, the entering air is directed by the reversing valve H into the air regenerator, as shown by the arrows, and there becomes heated ready for entering the furnace; at the same time the gas entering from the gas flue I, Fig. 7, is directed by the reversing valve J into the gas regenerator, where it becomes heated to the same temperature as the air. Similarly the products of combustion on leaving the opposite end of the furnace pass down through the second pair of regenerators, as shown by the arrows in Fig. 4, and after being here deprived of their heat are directed by the reversing valves H and J into the chimney flue K. When the second pair of regenerators have become considerably heated by the passage of the hot products of combustion, and the first pair correspondingly cooled by the entering air and gas, the valves H and J are reversed by the hand levers, as shown dotted in Figs. 7 and 8, causing the currents to pass through the regenerators and the heating chamber in the contrary direction, whereby the hot pair of regenerators are now made use of for heating the gas and air entering the furnace, while the cool pair abstract the heat from the products of combustion escaping from the furnace. The supply of air and gas to the furnace is regulated by the adjustable stop valves L, whereby the nature and volume of the flame in the furnace may be varied at pleasure; whilst the chimney damper is used to regulate the amount of pressure in the furnace in relation to the atmosphere, so as to allow the opening of working holes.

The construction of furnace above described may be varied in many ways to suit local circumstances. The regenerators are in some instances not placed immediately under but at the side of the furnace; but it is important that they should always be placed at a lower level than the furnace, in order that the air and gas may rise naturally into the heating chamber, forming there a plenum of pressure.

Plates 7, 8, and 9 show the application of the regenerative gas furnace as a Round Flint Glass Furnace. Plates 7 and 8 show vertical sections of the furnace taken at right angles to each other, and Plate 9 a sectional plan above and below the siege. The round form of furnace is found convenient in flint glass houses, affording the greatest amount of accommodation to the glass blowers. The four regenerators C are here arranged below the siege as before, and the air and gas from the hot regenerators enter the annular heating chamber A at one side of the furnace, as shown by the arrows in Fig. 10, and pass all round it, the products of combustion escaping at the opposite side into the cold regenerators. The direction of the current is reversed at intervals exactly as in the plate glass furnace already described, by means of the reversing valves H and J in the air and gas passages, Figs. 11 and 12. Furnaces of this construction have lately been got to work at Namur in Belgium and at Montluçon in France, and several others of the same description are in course of erection at the present time. The furnace just started by Messrs. Osler in Birmingham also partakes of this form, being made semicircular.

In setting out each individual furnace, the heating effect required, the quality of the fuel employed, and the particular nature of the process to be performed, have to be considered. The amount of heat required determines the capacity of the regenerators; and the gas regenerators require fully as large a capacity as the air regenerators, and sometimes even a greater. This would perhaps hardly be expected, but will be seen to be the case from the following considerations. The gases proceeding from the gas producers are a mixture of olefiant gas, marsh gas, vapour of tar, water and ammoniacal compounds, hydrogen gas and carbonic oxide; besides nitrogen, carbonic acid, some sulphuretted hydrogen, and some bisulphuret of carbon. The specific gravity of this mixture averages 0·78, that of air being 1·00; and a ton of fuel, not including the earthy remnants, produces according to calculation nearly 64000 cubic feet of gas. By heating these gases to 3000° Fahr. their volume would be fully six times increased, but in reality a much larger

increase of volume ensues, in consequence of some important chemical changes effected at the same time. The olefiant gas and tar vapour are well known to deposit carbon on being heated to redness, which is immediately taken up by the carbonic acid and vapour of water, the former being converted into carbonic oxide and the latter into carbonic oxide and pure hydrogen. The ammoniacal vapours and sulphuretted hydrogen are also decomposed, and permanently elastic gases with a preponderance of hydrogen are formed. The specific gravity of the mixture is reduced in consequence of these transformations to 0·70, showing an increase of volume from 64000 to nearly 72000 cubic feet per ton of fuel, taken at the same temperature. This chemical change represents a large absorption of heat from the regenerator, but the heat is given out again by combustion in the furnace, enhancing the heating power of the fuel beyond the increase due to elevation of temperature alone.

The chemical transformation is also of importance in preventing "sulphuring;" for it is believed that the sulphur in separating from its hydrogen takes up oxygen supplied by the carbonic acid and water, forming sulphurous acid, a firm compound, which is not decomposed on meeting with metallic oxides in the furnace. This view is so far borne out by experience that glass containing a moderate proportion of lead in its composition may be melted in open crucibles without injury, instead of requiring covered pots for the purpose as in ordinary furnaces. In dealing with the highest quality of flint glass however it is found necessary to retain covered pots; but every other description of glass is melted in open pots. In all branches of glass manufacture, saving of fuel is of relatively small moment as compared with the improvement effected in the colour and general quality of the glass by the use of the regenerative gas furnace, owing to the absence of dust and cinders and the higher degree of temperature which may with safety be maintained throughout the heating chamber.

These advantages of the regenerative gas furnace are of equal value in the case of puddling and welding iron. Plates 10 and 11 represent a Puddling Furnace constructed on this plan. Fig. 13 is a longitudinal section of the furnace, Fig. 14 a sectional plan of the

puddling chamber, and Fig. 15 a sectional plan of the regenerators; Fig. 16 is a transverse section at the end of the furnace, and Figs. 17 and 18 are vertical sections through the gas and air passages.

The four regenerators C are in this case arranged longitudinally underneath the puddling chamber A, which may be of the usual form. In order to complete the combustion of the gas and air in passing through the comparatively short length of the puddling chamber, it is necessary to mix them more intimately than is requisite in the large glass furnaces previously described. For this purpose a mixing chamber O, Fig. 13, is provided at each end of the puddling chamber, and the gas and air from the regenerators are made to enter the mixing chamber from opposite sides, as shown in Fig. 16; the gas aperture E is moreover placed several inches lower than the air aperture F, so that the lighter stream of gas rises through the stream of air while both are urged forward into the puddling chamber, and an intense and perfect combustion is produced. The mixing chambers O are sloped towards the furnace, as shown in Fig. 13, in order to drain them of any cinders which may get over the bridge. The reversal of the current through the furnace is effected about every hour by the reversing valves H and J in the air and gas flues, the arrangement of which is exactly similar to that already described in the glass furnace: the supply of gas and air is regulated by the throttle valves L, and the draught through the furnace by the ordinary chimney damper.

This same arrangement, with obvious modifications, may be applied also to blooming and heating furnaces, the advantages in both cases being a decided saving of iron, besides an important saving in the quantity and quality of the fuel employed. The space saved near the hammer and rolls by doing away with fireplaces, separate chimney stacks, and stores of fuel, is also a considerable advantage in favour of the regenerative gas furnace in ironworks. The facility which it affords for either concentrating the heating effect or diffusing it equally over a long chamber, by effecting a more or less rapid mixture of the air and gas, renders the furnace particularly applicable for heating large and irregular forgings or long strips or tubes which have to be

brought to a welding heat throughout. It has already been applied to a considerable extent in Germany for heating iron, having been worked out there under the direction of the writer's eldest brother, Dr. Werner Siemens, who has also contributed essentially to the development of the system. The furnaces at the extensive iron and engine works of M. Borsig of Berlin are being remodelled for the adoption of this system of heating, as have also been those at the imperial factories at Warsaw.

Another important application of the regenerative gas furnace is as a Steel Melting Furnace, in which the highest degree of heat known in the arts is required, presenting consequently the greatest margin for saving of fuel. Plate 12 represents a regenerative steel furnace which has been in satisfactory operation in Germany for a considerable length of time, being worked with lignite, a fuel little superior to peat in heating power. This application of the regenerative gas furnace is indeed rapidly extending in Germany, but has not yet practically succeeded in Sheffield where it was also tried: it is however in course of application at the Brades Steel Works near Birmingham. Fig. 19 is a longitudinal section of the furnace, Fig. 20 a transverse section, and Fig. 21 a sectional plan.

The two pairs of regenerators C C, Figs. 19 and 21, are situated at the ends of the long melting chamber A, in which the steel melting pots B B are arranged in a double row. The chamber is covered with iron cramped arch-pieces P, any of which can be readily removed for getting at the pots. The arrangement of the reversing valves and the air and gas flues is similar to that in the glass furnace previously described.

Other applications of the regenerative gas furnace are being carried out at the present time: among which may be mentioned one to brick and pottery kilns for Mr. Humphrey Chamberlain near Southampton, for Messrs. Cliff of Wortley near Leeds, and for Mr. Cliff of the Imperial Potteries, Lambeth; also to the heating of gas retorts at the Paris General Gas Works, and at the Chartered Gas Co.'s Works, London. The description already given however is sufficient to show

the facility with which this mode of heating may be adapted to the various circumstances under which furnaces are employed. The important application of the regenerative system to hot-blast stoves for blast furnaces by Mr. E. A. Cowper has already been separately communicated to this Institution (see Proceedings Inst. M. E., 1860, page 54).

The experience hitherto obtained with the regenerative mode of heating shows that it is attended with the greatest proportionate advantage in localities where good coal is scarce but where an inferior fuel abounds. This applies most forcibly to the South Staffordshire district, where the best coal in lumps is worth 12*s.* 6*d.* per ton, whereas good slack can be had at 3*s.* or 4*s.* per ton. The question gains moreover in importance when it is considered that, according to the best authorities, the Thick coal of the district is coming to an end, while millions of tons of coal dust have accumulated, of no present commercial value, which on being converted into gas in the manner described by means of the gas producers would acquire a heating value equal at any rate to the same weight of the best coal in the manner in which it is at present used. Considering also the proximity of the pits to the ironworks in this district, it may be suggested whether the gas producers being of very simple construction might not with advantage be placed near the banks of fuel above or even under ground, the gas being conveyed to the works by a culvert so as to supersede carting of the fuel. Such an arrangement might notably contribute to perpetuate the high position which South Staffordshire has so long maintained as an iron producing district.

Mr. Siemens observed that the essential features of the regenerative gas furnace described in the paper, as now matured and carried out in practice, were the separate gas producers, in which the solid fuel was converted into a gaseous form for use in the furnace, and the regenerators, in which the gas and air were each raised to a high

degree of temperature previous to their mixture and combustion in the furnace, whereby the heat produced by the combustion was very greatly increased. In the gas producers the fuel underwent a slow digestion, and the whole of the combustible constituents were drawn off into the furnace in the form of gas, while the incombustible ash or valueless portion of the fuel was left behind. The gas produced was of a crude nature in its original state, and much inferior to common gas for illuminating or heating purposes, and if burnt only with ordinary air would give very poor results: but it underwent a further change in the regenerator where it was heated up to about 3000° Fahr., at which temperature the several gaseous compounds contained in it became decomposed, the rich carburetted hydrogen depositing carbon which was at once taken up by the vapour of water present, producing carbonic oxide and hydrogen; so that there was then present the greatest amount of free hydrogen, which had three or four times the heating power of any other gas. The air used for burning the gas was also heated by the regenerator up to about 3000° and then mixed with the gas at the same temperature, producing perfect and most intense combustion: the regenerative system thus presented the means of attaining an almost unlimited degree of temperature. At the same time there was no great current or draught through the furnace, since the chimney draught was not required in this furnace to urge the combustion as in ordinary furnaces heated by solid fuel, and the cutting draughts destructive of ordinary furnaces were therefore entirely avoided.

Mr. J. T. Chance said the regenerative gas furnace had been tried at Messrs. Chance's glass works, and it certainly bid fair to produce a considerable change in the mode of maintaining the high temperature required in glass works. He was not in a position at present to state definitely that success was thoroughly obtained in every particular, simply because it required time to develop all the difficulties or peculiarities that might arise in the application of the furnace to a new process of manufacture, which might not be anticipated prior to actual trial. No difficulties however had occurred yet in the working of their large melting furnace, containing eight large pots holding two tons of glass each, which had now been

in regular work for three weeks with complete success; and there appeared no reason to anticipate any difficulty arising. On the contrary he expected the greatest advantages in glass furnaces from the plan of converting the fuel into gas before letting it enter the furnace, of the superiority of which there could be no doubt; for it was evident it must be far better to have gas alone burnt in the furnace, producing a perfectly clean flame, free from all impurities, than to have the gas generated from solid fuel in the furnace itself, when the work was necessarily exposed to all the impurities arising from the fuel, especially at the time of stirring up the fire. The economy of the furnace at their works had not yet been definitely ascertained, as it had not been long enough at work at present for that purpose, but he expected there would certainly be economy as compared with ordinary furnaces.

They had had a smaller furnace on the same principle at work previously for a year, for the purpose of making a preliminary trial of the plan before attempting to carry it out on so large a scale as the new furnace that had now been erected. In this first furnace some deposit had occurred in the regenerators, which he hoped would be obviated in the larger furnace. In making glass a great volatilisation took place of the foreign substances contained in the melted materials, which in the ordinary furnaces passed off through the working holes; but in the new regenerative furnace the volatilised gases would all have to pass through the regenerators, and he was desirous of seeing whether this would cause any trouble by choking the passages of the regenerators after working for a length of time: but even if any such effect were produced, it would be merely a question of expense of renewing the regenerators when required. The principle of the furnace was certainly a very perfect one, and on first becoming acquainted with it he was particularly struck with the scientific principle on which the regenerators acted, separating the heat passing off from the furnace, and retaining it all in the furnace, letting the products of combustion pass off into the chimney at a low temperature; and the quantity of heat thus gradually accumulating in the regenerator was then all given back again to the furnace when the draught was reversed. In the practical application of the regenerative furnace for glass making he had been surprised

that so few difficulties were met with, the new large furnace having gone on in regular work with entire success from the first start: the furnace thus appeared not only perfect in theory, but also to present no insuperable difficulties in practice.

The CHAIRMAN asked what was the experience at Messrs. Lloyd and Summerfield's glass works as to working and economy of fuel with the new furnace.

Dr. LLOYD replied that they had had one of the regenerative ten pot furnaces in operation nearly twelve months for flint glass making, and every month's experience of its working convinced him that the high opinion he originally formed of its value was fully deserved, notwithstanding some difficulties that had been met with. The regenerative system appeared to him one of the most beautiful adaptations of science to practical art, and he was so much struck with the soundness of the principle that he went at once to see a small glass furnace that was working on that plan in Yorkshire; and being satisfied of the theoretical perfection of the plan, he adopted the new furnace immediately at his own works for flint glass making. In this case the melting pots were all closed in at the top, and he had therefore no apprehension of the regenerators getting clogged after working a length of time, since all the vapours in melting escaped at the mouths of the pots and did not pass into the regenerators at all. Some inconvenience had arisen occasionally at first by pots breaking near the bottom, in consequence of the siege being too thin; but this was effectually remedied by raising the siege with fireclay by degrees in setting new pots. He had adopted the new furnace mainly with a view to saving in fuel, and particular attention had been paid to ascertain the real economy in this respect. It was built of about the same capacity as an old ten pot furnace, which they had had in use for several years previously, heated with large best coal; the large coal was found more economical in the end than coal of an inferior and cheaper description, but the consumption was very considerable. The result of the comparison between the two furnaces was that the old furnace consumed as nearly as possible double the quantity of fuel required in the regenerative furnace, the average of the year being about 35 tons per week in the old and only 16 to 17 tons

per week in the new: but the coal now used in the new furnace cost only one third as much per ton, being entirely small coal at *4s.* per ton instead of large coal at *12s.*; so that the actual cost of fuel in the new furnace was reduced to one sixth of that in the old, doing the same amount of work.

This was a very important economy in manufacture, but there were also other prospective advantages in the new furnace to be taken into account, in respect of durability and maintenance. In the old furnaces the cost and inconvenience of rebuilding were a serious consideration; but the durability of the new furnace seemed likely to be much increased by the heat being kept so equable, with an entire freedom from cutting draughts: the experience of the twelve months' working of their new furnace was that the wear and tear were so trifling, although a very high temperature was maintained, that he expected it would last three or four times as long as the old furnace, judging from the state of the edges of the bricks in the new furnace, which were still nearly as sharp as when it was built. This increased durability might indeed be reasonably anticipated, because no alkaline and earthy matters from the fuel were now carried into the furnace but they were all left behind in the gas producer, and nothing went into the furnace but gases that were wholly combustible and almost entirely free from impurities. The flame produced was so pure that they were now able to carry on the working as it is termed of the glass in the same furnace as the melting, instead of in a separate heating furnace where the glass articles being worked were protected from the fuel: this was utterly impossible in the old furnaces heated direct by coal, because pure glass was completely spoiled in a few minutes if exposed to the flame of ordinary furnaces, and flint glass could not be melted in them except in covered pots to protect it from contact with the flame; but in the new furnace not more than 5 per cent. of the articles had been injured, and that was observed to occur only occasionally when there had been some irregularity in the working of the gas producers on account of their not having been correctly managed. The very uniform and intense heat obtained in the new furnace enabled the melting to be done quicker than before, improving both the quantity and quality of the make: a considerable saving might also be effected in the

proportion of fluxes required in the glass, a smaller quantity being necessary with the greater heat obtained. He considered that for all manufactures where a high temperature was required to be constantly maintained without risk of variations the regenerative gas furnace possessed great advantages and was deserving of careful attention.

Mr. W. Haden enquired whether in applying the new furnace for puddling there was any practical difficulty in varying the intensity of the flame in the puddling chamber to suit the state of the iron.

Mr. Siemens replied that there was no difficulty in keeping up an abundant supply of gas if there were enough gas producers and if the passages to the furnace were large enough; the puddling chamber could then be completely filled with flame at any moment, or the flame could be as instantly stopped, by means of the regulating valves and chimney damper. By having separate air and gas valves the chemical nature or heating power of the flame could also be regulated to any desired degree, by altering the proportion of air admitted with the gas, so as to produce any required effect from a smoky flame to a pure bright flame. In the furnace for flattening the cylinders of sheet glass a quantity of bright clean flame was required for softening the glass without melting it; but in the melting furnace on the contrary an intense soaking heat was wanted with very little variation: and both sorts of heat were obtained in the new furnace from the same gas main, by simply regulating the quantities of air and gas admitted. Of the puddling furnaces two were now just being started in the South Staffordshire district, but about twenty puddling and heating furnaces had been at work in Germany for some months already with complete success.

The Chairman asked how long it took to work off a heat in puddling in the regenerative furnace.

Mr. Siemens said they had not yet obtained any absolute results with the regenerative puddling furnaces in this country, but at present the time of working a heat was about the same as in the ordinary puddling furnaces. The puddling furnaces working on this plan near Wolverhampton were not yet in a complete state for operation as they had been expected to be before this time, on account of a defect in the chimney flue and in the drainage of the premises. No permanent

difficulty could be anticipated in carrying out the new puddling furnace in practice, on account of the large amount of experience gained in the application of the regenerative furnace for other purposes.

Mr. T. W. Plum asked whether the draught was obtained by a separate chimney to each furnace as in ordinary puddling furnaces.

Mr. Siemens replied that there was only one chimney to a number of furnaces, and the draught was simply regulated by a separate damper to each furnace. The chimney was not required to be lined with firebrick, but was built of red bricks, as the heat passing off from the puddling chamber was all arrested in the regenerators and the chimney was always cool. The chimney damper regulated only the force of draught in each furnace, but the quantity and quality of flame were regulated by the gas valve.

Mr. W. Mathews enquired whether there was any tendency in the regenerators to fur up with deposit from the inferior description of fuel used for the furnace.

Mr. Siemens replied that no such result had taken place in the regenerators, because the steam mixed with the gas would volatilise any carbon that might otherwise be deposited on the walls of the regenerator : it was for this purpose that care was taken to supply an excess of vapour of water from the water trough in the grate of the gas producer.

Mr. W. Mathews asked whether the materials of the furnace were not liable to vitrify under the great heat to which they were exposed, and whether any limit had been found to their endurance.

Mr. Siemens replied that a regenerative heating furnace had been three years in constant work at Messrs. Marriott and Atkinson's steel works, Sheffield, heating the steel for the rolling mill, and no inconvenience had been experienced from this cause. Mr. Atkinson was prevented from being present at the meeting himself as he had wished, but had sent a letter expressing his satisfaction with the furnace, as especially advantageous for heating steel on account of the uniformity of the heat obtained in it. The glass melting furnace at Messrs. Lloyd and Summerfield's had also been in constant work for nearly a year without sustaining any injury from the great heat employed in it.

Mr. W. Mathews asked whether the temperature was really as high as had been supposed in the glass furnace; and what means were used for correctly measuring the degree of heat.

Mr. Siemens said the temperature in the furnace was at least a full welding heat of iron, as a bar of iron held in it dropped melted in half a minute; the hot end of the regenerator had a temperature of about 3000° Fahr., and the heat in the furnace must of course be greater. For measuring such high temperatures he made use of the pyrometer described at a previous meeting (Proceedings Inst. M. E., 1860, page 59), consisting of a well protected vessel containing a measured quantity of water, and a piece of copper or platinum of definite size, which was exposed for a sufficient length of time to the heat to be measured and was then dropped into the water; the rise of temperature produced in the water showed the degree of heat upon a thermometer scale graduated in the proper proportion, and the results thus obtained must certainly be correct within 10° or 15° Fahr.

The Chairman enquired what were the results of working of the regenerative furnace at Messrs. Russell's tube works at Wednesbury.

Mr. B. L. Brown said they had had one regenerative furnace at work for three months at their works as a heating furnace for bending the wrought iron strips for the tubes, and it had given complete satisfaction: the temperature was kept up constantly with great regularity, and there was no fear of the iron being unequally heated in different parts of the furnace or being injured by any impurities in the fuel. Another furnace on the same principle for welding the tubes had now been added at their works, but it had been in full operation for only about three weeks, and a definite statement of the results could not therefore be given; but up to the present time it had also proved thoroughly successful.

Mr. S. H. Blackwell had seen the regenerative furnaces at Messrs. Chance's and Messrs. Lloyd and Summerfield's glass works, and was exceedingly pleased with their operation. It would be premature to say much about puddling with the new furnace till it had been longer at work and afforded definite results; but he certainly thought there were some points about it which would be of the greatest benefit in puddling, particularly the saving of fuel by recovering all

the waste heat passing off from the puddling chamber, and the very efficient heat obtained for working the iron. Also the peculiar balancing of pressure for ensuring always a slight excess of pressure inside the furnace was an improvement of great value, preventing the cutting draughts that took place in ordinary furnaces through the puddling door and other openings, which caused a serious waste of the iron by oxidation. He had not yet had an opportunity of seeing the new puddling furnace at work, but had heard that one had been at work already about a month in the neighbourhood.

Mr. Siemens said that was the case, but the works happened to be just now stopped by the water being out of the canal; he understood however they were already starting to work again immediately.

Mr. S. H. Blackwell asked whether any results had been obtained as to the yield of iron in puddling with the new furnace.

Mr. Siemens replied that rather larger yields were obtained with the regenerative puddling furnace, but it had not been long enough at work yet to give any definite results. The puddling furnaces at work in Germany however showed at least 4 or 5 per cent. increase in the yield of iron, and this result was indeed to be expected, because the new furnace was free from the cutting action of the flame produced by a strong draught, and the ball was surrounded on all sides by an equally hot flame.

Mr. G. Thomson enquired what was the cost of applying the regenerative system to present puddling furnaces.

Mr. Siemens replied that the alteration of present furnaces would be attended with a considerable expense, as there was all the extra bottom brickwork of the regenerators, besides the separate gas producers and the valves and mains; but the separate chimneys for each furnace were saved, and the cost of maintenance was greatly reduced, judging from the condition of the glass furnaces that had been twelve months at work. In new works however the cost of construction of the regenerative puddling furnaces would not much exceed the total cost of the present furnaces complete; and the new furnaces had the advantage of occupying only their own space, without requiring room for a coal pen to each furnace; they could thus be built closer together and consequently more could be brought within reach of one hammer.

The CHAIRMAN enquired whether the pig iron was heated before being put into the puddling furnace.

Mr. SIEMENS said it was not heated, but put in cold.

The CHAIRMAN enquired what was the cost of the new puddling furnace, taking that of an ordinary furnace at about £150.

Mr. SIEMENS thought a pair of the new puddling furnaces would cost about £300 complete. The regenerative glass furnaces hitherto erected had been very expensive in construction, having heavy iron plates in the sieges and a great deal of ironwork in the fittings of the furnace and in the gas producers, much of which had been greatly reduced or dispensed with in the furnaces subsequently put up. In starting the new plan of furnace he had thought it best to keep all the work very substantial, to be on the safe side for strength and durability; and the gas producers had also been provided each with a separate gas tube and valve, so that each could be shut off from the furnace if desired, to avoid risk of the furnace being interfered with in its working by a defect at any particular point.

Mr. J. T. CHANCE observed that one other circumstance that ought to be mentioned about the regenerative furnace was the complete absence of smoke, which was a considerable advantage in its favour: excepting at distant intervals when the tar was being burnt out from the gas mains, there was really no smoke at all from the chimney, the combustion of the gases in the furnace being perfect. In large towns freedom from smoke was so great an advantage that this of itself would be a sufficient reason for adopting the regenerative furnace, even if in other respects it were only as good as ordinary furnaces, instead of being as he had found it so much superior to them.

Mr. E. A. COWPER thought the application of the new furnace in ironworks as a mill furnace would be attended with great advantages and would not involve any serious difficulty. It would be particularly advantageous for large work, such as heavy shafts of very large diameter, as it would afford the means of getting a soaking heat through to the centre of the mass, without any fear of injuring the iron by burning, since there was no free oxygen present in the furnace, as the whole of it was completely burnt at the moment of entering the furnace.

The CHAIRMAN observed that the subject of the paper was one of great interest and importance, and moved a vote of thanks to Mr. Siemens for his paper, which was passed.

After the Meeting a number of the Members dined together in celebration of the Fifteenth Anniversary of the Institution.

PROCEEDINGS.

24 April, 1862.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 24th April, 1862; Alexander B. Cochrane, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Thomas Bouch,	Edinburgh.
William Carpmael,	London.
James Clark,	Leeds.
Samuel H. F. Cox,	Birmingham.
Samuel Hingley,	Dudley.
J. C. Frank Lee,	London.
Wilson Lloyd,	Wednesbury.
Richard Christopher Mansell,	Ashford.
Frederick Thorpe Mappin,	Sheffield.
Edward Reynolds,	London.
William Simpson,	London.
John Taylor, Jun.,	London.
Charles Troward,	Doncaster.
Alfred Upward,	London.
Josiah Vavasseur,	London.
Francis William Webb,	Crewe.
Henry Arthur Webb,	Stourbridge.
Charles Wells,	Bilston.

The following paper was then read:—

ON THE CONSTRUCTION OF LIGHTING APPARATUS FOR LIGHTHOUSES.

By Mr. ARMAND MASSELIN, of Birmingham.

The subject of Dioptric Lighthouse Apparatus is intimately connected with that of a paper read at a former meeting of the Institution, namely, iron lighthouse towers (see Proceedings Inst. M. E., 1861, page 15); and the construction of the optical part of this apparatus is of considerable mechanical interest.

The construction and illumination of lighthouses constitute one of the most important of public undertakings at the present day. The development however of the comparative perfection now attained in these two departments has been gradual and unequal. During the century that has elapsed since the erection by Smeaton of the Eddystone lighthouse, when engineering was greatly in advance of practical optics, the art of building towers has received few improvements, while the apparatus for illuminating them has by the introduction of the dioptric system acquired a striking degree of excellence. During nearly the whole of the last century and in some places as late as 1816, open coal fires, improved occasionally by a flat brass plate placed on the land side, were the rude means usually resorted to for producing light. The Eddystone tower had a lantern to protect the weak light given out by the few miserable tallow candles which were then used, and only in 1807 were these replaced by lights furnished with silver-plated parabolic reflectors. Distinction of one light from another by its appearance at night, a point nearly as important as the range of the light, was of course out of the question.

Lights on the catoptric or reflecting system, composed of silver-plated parabolic reflectors provided with plain cylindrical burners

placed in the focus of each, were used exclusively until 1822, when Augustin Fresnel invented and erected on the Cordovan tower his first dioptric or refracting light. The catoptric or reflecting system was, in comparison with the imperfect means previously available, a valuable improvement, and under later modifications is still in extensive use in this country; but having many serious imperfections it is gradually disappearing before the dioptric or refracting system.

The latest optical and mechanical improvements in the dioptric system are illustrated by the fixed light of the Smalls Rock near Milford Haven, and the revolving light of Lundy Island, both constructed by Messrs. Chance, and the latter attested by mariners as the most powerful light in Great Britain, flashing over 35 miles of the Atlantic. In the present paper it is intended only to notice briefly the existing state of reflecting and refracting apparatus and the relative merits of each, before giving the particulars of their mechanical construction.

In the Dioptric or refracting system, only one lamp is used, placed in the vertical axis of the apparatus. In fixed lights, as shown in Fig. 1, Plate 13, the middle or dioptric part having the lamp in its centre is cylindrical, and composed of a series of refracting rings or lenses A A, shown black, which are so shaped as to give a horizontal direction to all the rays of light that fall from the lamp upon their inner faces. All the rays of light passing above and below these middle lenses are received by the upper and lower catadioptric prisms B B, shown black, by which they are also transmitted horizontally after refraction and total reflection in the prisms. Every piece of glass in the apparatus forms a portion of a horizontal ring or belt, having its centre in the vertical axis of the apparatus, as shown in the plan, Fig. 3, Plate 15. The rays of light given out by the lamp are thus collected and transmitted equally over the horizon, and the light is rendered luminous throughout its entire height. The glass prisms are fixed in eight gun-metal standards, forming an octagonal frame, each prism being supported in the centre by passing through an intermediate standard, as shown in the plan, Fig. 3.

In revolving lights, as shown in Fig. 2, Plate 14, the transverse section of the refracting lenses A and prisms B is precisely the same as in fixed lights: but in revolving lights the rings of glass are concentric round a horizontal axis passing through the brightest part of the flame, as shown by the dotted lines in Fig. 2, instead of round the vertical axis. The circumference is divided into eight flat faces, as shown in the plan, Fig. 4, Plate 15, each composed of a series of prismatic rings and segments having one common focus; the light emanating from the lamp is thus transmitted by each face in a brilliant flash extending over the whole width and height of the face; and the whole apparatus being made to revolve by clockwork, every point of the horizon is illuminated by a succession of brilliant flashes corresponding to the several faces, and at intervals of time determined by the speed of revolution. By the use of fixed and revolving lights or combinations of them in various ways, lights of distinct appearance are produced in a number sufficient for all purposes that are required in practice.

Dioptric lights are made of six different sizes or "orders" as they are termed; and the following table gives the internal radius of the apparatus or the focal distance in each order, the number of wicks in the lamp, and the consumption of oil in lbs. per hour, and in gallons per year, assuming the light to burn 11 hours per night on an average throughout the year.

Orders of Dioptric Lights.

Order.	Internal radius of Light.	Number of Wicks.	Consumption of Oil. Lbs. per hour.	Consumption of Oil. Gallons per year.
	Inches.		Lbs.	Gallons.
First	36·22	4	1·65	736
Second	27·55	3	1·10	490
Third	19·68	2	0·41	130
Fourth	9·84	2	0·26	116
Fifth	7·28	1	0·17	76
Sixth	5·90	1	0·17	76

The three largest orders are generally termed sea lights, and the three smaller ones harbour lights. The first order as the most important will alone be referred to in this paper, the others differing merely in size and number of prisms and lenses.

In the Catoptric or reflecting system a number of parabolic reflectors are used, ranged round a framework according to the purpose required, with a lamp in the focus of each reflector. In a fixed light these reflectors, frequently as many as 24 or 30 in number, are arranged round the frame so as to equalise the light as much as possible in all directions. In revolving lights the reflectors are mounted on a revolving frame, having generally three faces, each of which carries an equal number of reflectors. Three flashes of light are thus produced, which illuminate successively every point of the horizon at intervals regulated by the speed of revolution. The loss of light in this system is necessarily very large: indeed nearly the whole of the light from the front of the flame is directly lost by natural divergence, the reflectors transmitting to the horizon only the rays emanating from the back of the flame, and of this light nearly 50 per cent. is lost by the absorption that always takes place in reflection by metallic surfaces.

Comparing the two systems together, it is evident that for fixed lights no possible combination of reflectors can distribute a zone of light of equal intensity round the horizon, whilst this effect is completely obtained by the dioptric system. It is found that whilst only 3½ per cent. of a plain open light would be available round the entire horizon, 17 per cent. is obtained by the use of the best reflectors, but 83 per cent. is obtained by the use of the dioptric lights. The extreme divergence of the rays of light from a usual 21 inch reflector with a 1 inch flame is about 14 degrees; but the variation of the intensity of the flash emitted over this angle is very large indeed, the intensity of the light being only 16 per cent. on the sides of what it is in the axis of the flash, showing how great is the irregularity of the light spread over the horizon. Also the numerous fastenings of the reflectors and lamps frequently get loosened, increasing greatly the irregularity of

the light. Nor is the whole amount of divergence taken vertically useful; for, as will be shown afterwards, the lower portion of the vertical divergence required to illuminate the sea between the horizon and the land is but a very small amount. In uniformity of light therefore throughout the horizon illuminated the dioptric system is very greatly superior to the reflecting for fixed lights. With regard to economy of oil, fifteen reflector lamps together consume as much oil as the one central lamp in the dioptric light, and the saving therefore amounts to 50 per cent. in favour of the latter compared with a reflecting light of the largest practicable size, having thirty lamps, but greatly inferior in illuminating power to the dioptric light.

Another very important consideration is the durability of the apparatus. The longest time that reflectors will last, even when treated with the greatest care, is from 25 to 30 years; their thin silver coating will have completely disappeared at the end of that time. With moderate care and no necessity for readjustment dioptric lights may be considered as imperishable; the lenses and prisms never lose their correct form and first polish, never require renewal, and are kept always equally efficient with a far less amount of daily labour than that required for reflectors. The number of attendants or keepers required is the same in both cases, and the first outlay may be considered as generally equal.

For revolving lights however the catoptric system presents fewer points of inferiority as compared with the dioptric; for by sufficiently increasing the number of lamps and reflectors on each face of the revolving frame, a light of equal intensity to the dioptric might be produced. The illuminating power, consumption of oil, durability, and original outlay will therefore be the chief considerations to determine the relative advantages of the two systems for revolving lights. The effect of only one of the eight faces composed of annular lenses in a first order dioptric light is equal to that of eight of the largest reflectors in use, 21 inches in diameter; and consequently to produce by reflectors the effect of the best dioptric light a lantern would have to be provided capable of accommodating from 56 to 72 reflectors, an arrangement all but impracticable. Moreover at the time when most of the experiments were made both in this country

and abroad for comparing the intensity of revolving dioptric and reflecting lights, the dioptric lights were composed merely of the central or singly refracting part AA, Fig. 2, Plate 14. But in the present holophotal system, in which the upper and lower reflecting prisms BB are made to continue and extend the action of the central refracting lenses AA as already described, the intensity of the dioptric lights has been nearly doubled and the comparison rendered so much more unfavourable to the reflecting system.

The only objection which has been seriously urged against the dioptric system is the use of only a single central lamp, on account of any difficulty in its management affecting the whole light, or danger of its sudden extinction. This is met however by the successful experience of forty years with an immense number of lights in different parts of the world. Hardly ever has such a case occurred; and as spare burners are invariably supplied and required to be always kept ready for use, a few minutes only would suffice to remove the defective burner and replace it by another.

The Lamp necessarily forms a very important part of the lighthouse apparatus, in the efficiency of which it is an essential element. The lamps generally used in the larger dioptric lights are of the class known as mechanical lamps, in which the oil is forced from a reservoir into the burner by means of a pump worked by clockwork driven by a weight. Although this construction of lamp is simple enough, it requires that the keepers should be trained to its use and should have a thorough knowledge of the way of taking it to pieces for cleaning and then putting it together again, before they are sent to their respective lighthouses. As this precaution was not at first universally adopted in lighthouses, complaints were made against the mechanical lamp; and in consequence lamps of the simplest possible construction but inefficient in action came into use in this country, consisting simply of a side reservoir communicating by a tube with the burner, the level of oil in both being the same. The consequent absence of overflow prevented a high flame from being obtained and greatly impaired the efficiency of the light, which doubtless considerably retarded the adoption of the dioptric system. Pressure lamps were also made more

lately, consisting of a large cylindrical oil reservoir containing a piston fitted with a cupped-leather packing, the pressure being obtained by a number of small weights arranged round the piston, whereby the oil was forced through a side tube into the burner. These lamps however presented many inconveniences: the pressure could not conveniently be varied, since the addition of one weight tended to cant the piston out of its horizontal position and allow the oil to escape at the opposite side. The cylinder being made only of sheet brass and therefore not perfectly cylindrical, a considerable difference of diameter between the piston and cylinder was required; and when the oil became rather warm, the leather got so soft that it was liable to turn over and render the lamp useless. The piston being entirely submerged lost a portion of its weight; and whenever the pressure had to be varied, the weights taken out were covered with oil, and there was a great waste by the oil being spilled: there was also a liability to leakage from the body of the lamp being made of several parts soldered together.

The conditions the lamps are required to fulfil are:—a constant and even supply of oil to the burner, equal to fully four times the consumption; simplicity of construction, so that any unskilled mechanic can take the lamp to pieces and put it together again; freedom from liability to derangement; and an accurate fit of the various parts, so that all duplicate parts will fit equally well.

To meet these requirements the writer designed the construction of lamp shown in Fig. 5, Plate 16, which has fully answered the purpose. The brass cylinder C, containing the oil for the lamp, is cast solid in one piece with the bottom, and bored out truly cylindrical, and is fitted with a turned piston D having a cupped-leather packing; the three piston rods are connected at top to a wrought iron ring E, Fig. 6, to which are attached the side rods passing down outside the cylinder to the wrought iron ring below, which carries the weight F. The piston is steadied against any small lateral oscillation by six leather guides G fixed round its circumference; and any air underneath is let out through the centre vent cock H. The oil is forced out at the bottom of the cylinder through the upright tube I leading to the burner J, the quantity

being accurately adjusted by a conical regulating valve K, having an index on the screwed handle which shows the quantity of oil supplied to the burner per minute or per hour. When the piston has descended to the bottom of the cylinder, it is wound up again by the rack and pinion L, Fig. 7, underneath the cylinder; and the oil is prevented from being drawn down from the burner by a check valve consisting of a small ball M situated in the feed pipe I. The burner remains therefore constantly fully supplied with oil; and the time occupied by winding up the weight being only a few seconds, the overflow of oil is not even visibly affected. As impurities from the charring of the wicks, and especially a quantity of flue or dust from the cotton wicks, are constantly brought into the cylinder by the overflow oil and afterwards drawn under the piston, these would find their way up through the feed tube I into the burner J, which would cause a stoppage of the supply of oil to the wicks. To prevent this, a fine wire sieve N is placed in a box in the feed tube I, which arrests any impurities in the oil and can be opened and cleaned out occasionally in the day time when required. Should the sieve get stopped up during the night while the lamp is burning, it can be changed in less than a minute, which does not interfere with the working of the lamp. Each wick is provided with two oil tubes, whereby a constant supply of oil to each wick is obtained, instead of all the wicks being fed by a single exterior tube, as in the previous lamps.

In order to produce a proper illumination of the horizon by this light, it is essential that the full height of flame should be kept up, maintaining the flame correctly in the focus of the apparatus, without which the best optical apparatus would be imperfect in action. For this purpose the overflow of oil must never be less than three or four times the actual consumption; otherwise the wicks will burn down to the edge of the burner, and the intense heat produced would very soon destroy the burner itself. Moreover when the supply of oil is too small, the heat of the flame has time to act on the small overflow, and considerably deteriorates the quality of the oil; and the overflow being all returned into the reservoir, the quantity of deteriorated oil in the reservoir increases until it is impossible to maintain a good flame.

The proper shape, diameter, and position of the shoulder or contraction O, Fig. 5, in the glass chimney used for the lamp is of special importance, since this has a direct influence upon the shape and height of the flame and consequently upon the intensity of the light produced. Too sudden a contraction of the glass causes the flame to be reduced in height, especially that of the outer wick; and no efficient flame can be obtained unless all the wicks give a flame of equal height. Too large or too high a shoulder of the glass prevents a rapid combustion, and consequently prevents a bright flame from being obtained, and a long flickering one is the result. An adjustable damper is placed over the glass; and above this a continuous pipe of about 6 feet in length from the burner is required to produce a sufficiently rapid draught to support the combustion. When the lamp is lighted at first, the wicks are kept low for some time and gradually made to rise for about twenty minutes, until they rise about ¼ inch to ⅜ inch above the burner; then by a slight adjustment of the wicks to obtain equal height of flame, and the occasional shutting or opening of the damper P, Figs. 1 and 2, a most intensely bright and high flame is obtained and kept up during the whole of the night. The diameter of the burner and flame of a first order lamp is 3½ inches, and with proper management the flame is kept up constantly to a nearly uniform height of 4 inches.

The oil used in lamps for lighthouses is the refined colza oil or rape-seed oil, which is the only oil fit for the purpose and is much superior to the sperm oil formerly used, and is also cheaper. It burns with a brighter flame and does not cause so much deposit on the wicks, which therefore burn much longer without requiring to be trimmed. It also requires far more intense cold to thicken it than other oils, and there is therefore much less need for the small auxiliary frost lamp used in frosty weather for warming the oil in the main lamp. The thickness of the wicks is another point to be attended to, as a thin wick gives a brighter flame than a thick one under the same circumstances. When a lamp is in proper condition, supplied with proper materials, and in the hands of a moderately careful attendant, the flame can be kept up for fully seventeen hours to its full size, untouched, without requiring to have the wicks trimmed. The quantity

of oil consumed in a dioptric light during a given period is thus to a certain extent a test of the efficiency of the light, as it indicates the height of flame kept up during that time.

The construction of the apparatus for producing the revolution in revolving lights is shown in Fig. 2, Plate 14, which represents a revolving light recently constructed by Messrs. Chance for Russia.

The revolving platform D carrying the optical apparatus is mounted on a large cast iron pedestal E, within which is placed the clockwork G for producing the revolving motion. The revolving platform D is carried on twelve gun-metal rollers HH, centered on a live roller frame I, running round a fixed centre shaft J on the top of the pedestal. The roller paths on the top of the pedestal E and the underside of the revolving platform D are of steel; and the rollers H are fitted on their spindles with washers of different thickness, to allow of slightly varying their positions from time to time, in order to avoid grooving the paths by running constantly in one line. The driving motion is communicated from the clockwork G by a pinion gearing into an internal toothed wheel K on the underside of the platform D. Formerly a simple spur wheel worked by the pinion was used, but it was found that the motion was never steady enough in this mode of driving, on account of the small number of teeth in contact and the backlash between them: but with an internal wheel the number of teeth in gear at a time is much greater, and the motion is rendered much more smooth and regular. The clockwork G is driven by a heavy weight, and the speed is regulated by a pair of flies on the flywheel L, which are adjusted to the proper angle for controlling the motion to the required speed. The whole of this improved arrangement of clockwork and pedestal was devised by Messrs. Stevenson of Edinburgh for the service of the Northern Lights, where its constant use for many years has proved its great superiority over the arrangements adopted in all other revolving lights.

The optical apparatus itself is of an octagonal shape, as shown in the plan, Fig. 4, Plate 15, and the frame is constructed entirely of gun-metal. The catadioptric prisms BB composing the upper and lower portions of the light are fixed in the eight gun-metal standards

of the frame; but the lenses A forming the central portion are carried in separate frames, bolted to the standards, with a slight clearance left at the top, to prevent the risk of any weight coming on the rings of glass forming the lenses, which being in close contact with one another would give way under the least pressure. At the bottom the prisms B are omitted in one side to allow of access to the lamp C, which is erected upon a stand on the service table, as shown in Figs. 1 and 2. A copper ventilating tube M extends up above the lamp into the neck of the cowl, Fig. 8, Plate 17, on the plan introduced into the lighthouse service by Professor Faraday. The inverted funnels N placed at different levels in the ventilating tube afford a free escape to any accidental downward gust of wind, and thus prevent any risk of the lamp being blown out; and it is found by experience that the wind may blow in suddenly at the cowl, but the effect never reaches the lamp. The draught of the heated air in the tube M also draws off through the funnels a quantity of the air of the lightroom, thereby preventing condensation of the moist air upon the glazing of the room, which would otherwise interfere greatly with the efficiency of the light. A short length of the tube at the bottom containing the damper P, Figs. 1 and 2, is made to slide upwards, to allow of removing the glass chimney, but so as not to weigh on the glass or fall when the glass is taken out.

The Lantern, within which the whole of the lighting apparatus is contained, is shown in Fig. 8, Plate 17. It is of an octagonal shape, as shown in the plan, Fig. 9, Plate 18, and is 13 feet diameter, formed of cast iron panels with the joints planed to the proper bevil so as to fit solid together. The standards O supporting the dome of the lantern and forming the framing for the plate glass panes are inclined alternately right and left, which adds greatly to the stiffness of the structure, while the light is not entirely intercepted in any vertical plane, as would be the case if the standards were vertical. The standards are of wrought iron, of a bevil section, as shown enlarged in Fig. 11, Plate 18; to prevent corrosion by the action of the sea air they are protected along the outer edge with a gun-metal facing R, grooved to receive the plate glass panes S, which are then

secured in their places by thin covering strips of gun-metal screwed on outside. Two sets of gun-metal astragals T, Figs. 10 and 12, to support the glazing are fixed horizontally between the standards, at the level of the joints between the refracting lenses and reflecting prisms of the optical apparatus, so as not to stop any of the rays emanating from the light.

The glazing S of the lantern consists of panes of plate glass about ⅜ inch thick, the edges of which are ground and the arises bevilled to prevent breakage in fixing or in any possible shaking of the lantern in a violent gale. Small strips of lead are placed between the glass and the gun-metal frames, and the interstices are filled up with putty. The glass lies entirely within gun-metal frames, and there is no difficulty in replacing a broken pane at any time. To guard against an accidental stoppage of the light through breakage of a pane in a gale or by sea birds flying against the glass, storm panes are provided, made of a copper frame glazed with thick glass, which are kept always ready in the lightroom and can be fixed in a few minutes in place of a broken pane. The copper dome U, Fig. 8, Plate 17, forming the roof of the lantern, is made double, with an air space between; and the cowl V at its summit revolves with the weathercock, to turn the openings always from the wind, allowing a free escape for the heated air from the ventilating tube of the lamp.

The efficiency of a dioptric light depends entirely upon the proper adjustment of the various optical elements which compose it. The vertical divergence of the rays of light depends on the dimensions of the flame of the lamp, and seldom exceeds an angle of 5 degrees, which is amply sufficient for all practical purposes. For an angle of vertical divergence equal to one fourth of the dip of the horizon illuminates half the whole distance from the horizon to the lighthouse; and an angle of vertical divergence equal to the dip of the horizon illuminates three fourths of that distance. Within a mile or two from the lighthouse however an angle of vertical divergence equal to the dip of the horizon illuminates only a small fraction of a mile, showing how little is gained by increasing the vertical divergence at the sacrifice of brilliancy at the horizon. Thus for a tower of 100 feet height, about

1-6th of a degree (9′ 45″) is the amount of the dip of the horizon, and a further angle of the same amount illuminates the sea from the horizon towards the land for a length of 8½ nautical miles, the total range of the light being in this case 11¾ miles. For a tower of 200 feet height the dip is about 1-4th of a degree (13′ 46″), and a further angle of the same amount illuminates from the horizon a distance of 12 miles out of a range of 16 miles. These figures show that a vertical divergence equal to the dip of the horizon is quite sufficient to illuminate the sea from the horizon up to within a moderate range of the tower.

The efficiency of the light depends also upon its being correctly adapted in direction and divergence to the particular elevation it is intended to occupy, otherwise a portion of the brightest rays may pass above the horizon and consequently be lost, instead of being of service at and within the horizon. The dioptric system also affords peculiar facility for directing the light upon any particular point where it is more especially required. For instance: a light may be required merely as a sea light, for the purpose of signalling to mariners their approach to the land; in that case the most intense light of the whole apparatus is directed towards the horizon. Or a light may be required to illuminate the horizon, but most particularly the sea in the neighbourhood of the land, the approaches of a harbour, or some particular local danger; in that case the light of some portions of the apparatus is directed towards the horizon, and the light of the other portions is deflected towards the point requiring special illumination.

A specimen of one face of the optical apparatus, containing the lenses and prisms of a revolving light, was exhibited from Messrs. Chance's glass works, and also a specimen of the pressure lamp used for the most powerful lights.

The Chairman enquired what were the particular difficulties with the mechanical lamps formerly used in lighthouses, in which the oil was raised by pumps driven by clockwork.

Mr. Masselin replied that the old mechanical lamps were complicated in construction, and the clockwork for working the oil pumps had to be got into a confined space, being more like watchwork than clockwork, and requiring a skilled mechanic properly trained to manage it; and as lighthouses were generally situated at a distance from any town, it was a serious objection to have any liability of requiring to send away to get the necessary repairs done. The pressure lamps now used were of simple construction and stronger in all the parts, as shown by the specimen exhibited; they had no machinery about them requiring attention and there was therefore no liability of the light ever failing from the lamp getting out of order. Of course clockwork was still required for making the lights revolve, but this was so much stronger and larger that it was not liable to get out of order, and admitted of easy repair.

The Chairman asked whether the wicks in the lamp were all used at the same level, and what height of wick was required above the burner.

Mr. Masselin said each wick was raised independently of the rest by a separate screw, and all were turned up to exactly the same level, standing about $\frac{3}{8}$ inch above the burner, of which about $\frac{1}{4}$ inch became blackened by the flame, leaving $\frac{1}{8}$ inch steeped in the overflow of oil standing above the burner.

The Chairman enquired how the burner was replaced in case of its ever being injured by overheating from the wicks burning down too low.

Mr. Masselin showed that the entire burner together with the glass chimney was readily removed by simply unfastening two screws, and it could then be immediately replaced by a fresh burner, which was kept always ready at hand in the lightroom; but such a case never

occurred in practice while the light was burning at night, because the supply of oil was maintained constantly greater than the consumption, ensuring an abundant overflow, which prevented the wicks from burning down to the burner. The light was now kept up with such regularity that the wicks did not require any alteration during the whole night, after having been once adjusted to the proper level for producing a brilliant flame.

The Chairman enquired how the lamp could be removed if required at any time after the optical apparatus had been fixed in its place.

Mr. Masselin replied that there was ample room for getting out the lamp through the space left by either omitting the bottom panel of prisms on one side of the optical apparatus or hanging it on hinges. In the old lamps in which the oil cylinder was made roughly of sheet brass and therefore not truly cylindrical, the piston had to be made a very loose fit and the cupped-leather large; and the piston being loaded with weights upon it was liable to get unequally weighted when the weights were changed, so that the piston was canted and the leather turned inside out, rendering the lamp useless and requiring the piston to be taken out for re-setting the leather. This defect caused a prejudice at first against pressure lamps: but in the new lamps with the cylinder cast and bored no such accident could occur; and they were so strongly constructed in all the parts that there was now no more occasion for providing a duplicate lamp cylinder than for providing a duplicate optical or revolving apparatus; but duplicates were provided of all the working parts of the lamp which were in the least likely to wear. The weight giving the pressure on the piston was suspended below the lamp, and could readily be increased or diminished according to the degree of fluidity of the oil in the cylinder, without disturbing the action of the lamp.

The Chairman asked whether any of the fountain lamps were still in use, and what arrangement was adopted for fixing the oil reservoir so as not to interfere with the light.

Mr. Masselin said the fountain lamps were not all abandoned yet, but they were being gradually replaced as they became worn out by more efficient lamps. There was generally one side of the lighthouse towards the land on which the light was less wanted than on the

others, and the oil reservoir was then placed on that side just at the level of the burner.

The CHAIRMAN enquired what distance the dioptric lights were visible, and whether the whole of the light was confined in the vertical direction within so narrow a limit as only 5 degrees of divergence.

Mr. MASSELIN replied that the range of the light depended on the height of the lighthouse and consequent distance of the horizon: at Lundy Island in the Bristol Channel, where the lantern was about 540 feet above the sea, the horizon was about 35 miles distant and the light was distinctly seen at that distance. The power of the light at such a distance depended of course upon the concentration of the greatest possible amount of the rays within a very small angle, and the angle of 5 degrees was the maximum amount of vertical divergence in most cases. The extreme minuteness therefore of the angles to be dealt with rendered perfect accuracy of workmanship and adjustment in the optical apparatus of the utmost importance. The middle ray or axis of the light did not issue in a true dead level, but was deflected to the horizon, being depressed by the amount of the dip of the horizon, so as to throw the strongest part of the light full upon the horizon; and of the 2½ degrees or 150 minutes forming the lower half of the divergence, the first 10 minutes alone were sufficient to light three quarters of the distance from the horizon towards the lighthouse, in the case of a tower 100 feet high. If more of the light was wanted on the sea and less on the horizon, the axis was further deflected, so that the central rays fell on the sea nearer in than the horizon.

The CHAIRMAN asked what was the greatest distance for which reflecting lights were employed, and whether there were many of them now in use.

Mr. MASSELIN believed it was only in England and the English colonies that there were any lights remaining on the old reflecting system, as they had been entirely abandoned in other countries for dioptric lights, and in this country the present reflecting lights would no doubt be replaced by dioptric apparatus, as soon as the reflectors required renewal. He did not know what was the greatest distance illuminated by a reflecting light, but with a sufficient number of lamps and large reflectors there was no reason why as good a light should

not be obtained by the reflecting system, for revolving lights, as by the dioptric: but the cost of maintenance and consumption of oil was much greater in the reflecting system, and the whole of the reflectors required entirely renewing after a certain time of wear. The largest reflectors that he knew of were 21 inches in diameter, and the greatest number employed in any one light was from 24 to 30.

Mr. Sampson Lloyd thought the paper that had been read was of great value and general interest on account of the high degree of perfection attained in the apparatus, and also from the number of wrecks still occurring and the importance of efficient lighthouses for preventing them. He enquired what increase had taken place in the number of lighthouses since the introduction of the improved system of lighting, and how many dioptric lights there now were round the coast of England.

Mr. Masselin replied that eighty years ago there were no lighthouses deserving of the name, but only a few towers with coal fires to serve as beacons; and even as late as 1820 several of the main lights, at Harwich and elsewhere, were only open coal fires with a brass plate placed behind as a rude kind of reflector. The celebrated Eddystone lighthouse was originally lighted by only a few miserable tallow candles, and in 1780 the first reflectors were used; but these were made only of plaster of paris, hollowed to a parabolic shape, having the inner face covered over with small pieces of ordinary mirror glass set in the plaster, which were replaced in 1807 by copper reflectors silvered on the face. The old reflecting system continued in general use until 1834, when Fresnel's more perfect dioptric light was introduced into this country, the first being erected on Lundy Island. The optical apparatus then consisted of only the annular lenses forming the central portion through which the light was simply refracted, without any of the catadioptric or totally reflecting prisms by which the light was now rendered luminous throughout the entire height of the apparatus. The number of lights now in use round the coast of England was altogether about 200, of which only about 38 were dioptric lights; but in the United States there were already more than 500 dioptric lights.

The CHAIRMAN asked in what manner the prisms were adjusted to their correct positions in the optical apparatus, and whether that was done before the apparatus was fixed at the lighthouse.

Mr. MASSELIN regretted that Mr. J. Chance had been unexpectedly prevented from being present to afford explanation of the optical portion of the apparatus. The principle of adjustment was that each prism of glass in the apparatus was separately adjusted and fixed at the correct angle for the ray from a distant fixed point to be directed in each case to a focus where the flame of the lamp was situated, so that all the rays intersected at that focus, and the whole of the light from the lamp was consequently deflected into the required direction towards the horizon. The height that the light had to be fixed above the sea being given, the angle of dip of the horizon was known, and the whole of this adjustment could consequently be made in the works by having a staff erected at a distance as the object to be viewed in making the adjustment of the prisms, the staff being graduated by calculation to correspond with the true direction of the rays if prolonged to the horizon from each line of prisms. A sight was fixed in the focus of the apparatus at the point where the brightest part of the lamp flame was to be, and each prism was separately adjusted until the image of a white line on the vertical staff was correctly thrown into the focus, a separate line for each prism being marked upon a staff specially graduated for each apparatus, according to the intended elevation of the lighthouse above the horizon. The adjustment was formerly in a few instances made at the sea coast, but by this arrangement it was now done at the works with much greater facility. Owing to the flame of the lamp being not a single point but extending over a height of as much as 4 inches in the largest size, the central rays only could be actually directed to the intended point, and the rays from the upper and lower portions of the flame gave a total divergence of the light of about 5 degrees vertically. Formerly, and still in France, the prisms were all set to a dead level, and on account of the dip of the horizon the central ray was consequently thrown above the actual horizon, and more than half the light was lost by being thrown into the air, instead of upon the sea; but here each prism was treated separately, and set so that its central ray was depressed to the horizon or to a point somewhat

within the horizon, so as to throw the greatest intensity of the light where it was most wanted for vessels approaching from a distance, and to make the greatest proportion of the light available.

The Chairman asked how the prisms were bedded and fixed in the gun-metal frames.

Mr. Masselin replied that during the process of adjustment the prisms were held in their places by small wooden wedges; and as soon as the adjustment was completed, they were secured by a little plaster of paris at three points of each, which set quickly, and the remaining space was filled in afterwards with white and red lead putty: this set very hard in a few days, and held the prisms secure in their right position, and prevented them from touching the metal frame anywhere, otherwise the glass would soon get chipped.

The Chairman observed that very great accuracy must be required in the form of the prisms, to ensure the correct direction of the rays, as any error would be so greatly magnified by the long distance; and enquired how the prisms were shaped to their correct form, so as to ensure each being a true figure.

Mr. Masselin replied that the required accuracy of work was obtained by doing the grinding and polishing of the prisms entirely by machinery of accurate construction. The prisms were set on horizontal revolving tables, like a horizontal face plate of a large lathe, up to 11 feet diameter, the prisms of the same section and the same curvature being fixed on the same table in a continuous circular ring of the required diameter, and having one face bedded in plaster of paris; the two other faces were then ground and polished in their position by a set of rubbers with emery powder and rouge, worked transversely by machinery as the table revolved, and moving at the required inclination or in curves of the required radius.

Mr. W. Mathews, Jun., enquired whether any chromatic aberration in the light was produced by its passage through the glass, as in the refraction of light through ordinary prisms.

Mr. Masselin said no appearance of prismatic colours was noticed in the light, and if there were any it was so slight as not to be perceptible, probably on account of the resolved coloured rays from the different prisms being so completely intermingled by the vertical

divergence of the light as to reproduce the white light free from prismatic colours.

The CHAIRMAN considered they were much indebted for the clear and valuable information given in the paper on a subject of such general importance, in which such extensive interests were involved. It was most necessary that the greatest possible perfection should be attained in the lighting apparatus of lighthouses, on the constant efficiency of which so many lives and vessels had to depend for safety. He proposed a vote of thanks to Mr. Masselin for the paper, which was passed; and also to Mr. James Chance for his kindness in lending the specimens exhibited.

The following paper was then read:—

ON THE COAL AND IRON MINING OF SOUTH YORKSHIRE.

BY MR. PARKIN JEFFCOCK, OF DERBY.

It is proposed in the present paper to consider the general features of the South Yorkshire district with reference to the circumstances affecting mining engineering.

The accompanying general plan, Fig. 1, Plate 19, represents that portion of the Yorkshire coalfield which is more particularly called the South Yorkshire district; extending from Sheffield on the south to Wakefield on the north about 25 miles, and from west to east about 20 miles altogether, on either side of Barnsley. The plan shows the general extent of the coalfield, indicated by the shaded portion; the outcrops of two of the principal seams of coal, the Silkstone and the Parkgate seams; the positions of the principal faults; the localities of the more important collieries and ironworks; and the lines of railway and water conveyance.

The horizontal section, Fig. 2, Plate 20, which is reduced from the late Mr. Thorpe's published section, is taken through Barnsley along the dotted line W E upon the plan, Fig. 1, extending from the millstone grit on the borders of Derbyshire on the west to the eastern boundary of the coalfield at E.

The vertical section, Fig. 3, Plate 21, represents the position and thickness of the principal beds of coal and mines of ironstone, as they were proved by borings at Wath Wood, near Lundhill Colliery on the plan, Fig. 1. Five beds of coal, between the Woodmoor seam and the Kent's Thin seam, do not occur at this place; a second vertical section, Fig. 4, is therefore placed alongside, showing these beds in their corresponding position as they were proved in sinking at the Oaks Colliery near Barnsley, Fig. 1.

The South Yorkshire coalfield is a continuation northwards of the Derbyshire coalfield. On the east it is bounded by the overlying and unconformable magnesian limestone and permian strata, and the extent of the coal measures in this direction is yet unproved. On the west the millstone grit rocks crop out, forming the bleak moors of North Derbyshire; and the coal measures extend northwards and constitute the North Yorkshire coalfield. The general dip of the coal strata is from west to east at an average angle of 1 in 9; this however is much modified in many localities by main faults, the principal of which are shown on the plan, Fig. 1, by the strong black lines. The total number of coal seams is very great, as shown in the vertical section, Fig. 3, and many of them have been worked in various localities.

The following are the principal seams of coal in their geological order, with their average thickness:—

1.	Wath Wood or Muck seam	4 ft.	6 ins. thick.
2.	Coal, no name	3	8
3.	Woodmoor seam	3	0
4.	Winter seam	5	4
5.	Upper Beamshaw seam	4	8
6.	Lower Beamshaw seam	2	2
7.	Kent's Thin seam	2	7
8.	Kent's Thick or High Hazel seam	5	0
9.	Barnsley Thick seam ... ... 8 ft. 6 ins. to	9	0
10.	Swallow Wood seam	5	0
11.	Howard or Flockton seam	5	0
12.	Fenton's Thin seam	2	3
13.	Parkgate or Chapeltown seam...	6	9
14.	Thorncliffe Thin seam	2	6
15.	Four Foot seam, variable	4	0
16.	Silkstone or Sheffield seam	5	0
17.	Charlton Brook or Mortomley seam	3	0

The most important seam of the series is the Barnsley Thick coal, which under the name of the Main or Top Hard coal has been very extensively worked in Derbyshire. In the South Yorkshire district its average thickness is about 8 feet 6 inches, but the thickness varies exceedingly at different places. It is most fully developed in the neighbourhood of Barnsley, but extends through the greater part of

the district, and has been principally worked at Woolley, Gawber, The Oaks, Edmund's Main, Wombwell Main, Darley Main, Elsecar, Warren Vale, Rawmarsh, Hoyland, Lundhill, Mount Osborne, Thryburgh, Darfield, Car House, &c. The hard coal from this seam is in great repute for steam purposes, and stood high at the trials made at Woolwich in 1851 relative to the value of steam coals. North of Woolley the Barnsley seam is subdivided into two or three others, which are worked in the neighbourhood of Normanton under different names. In Derbyshire it appears to the best advantage at the large works of Mr. Barrow at Staveley, where it is known as the Staveley Hard coal, which has been extensively used for steam purposes and in the manufacture of iron.

The Swallow Wood seam occurs about 60 yards below the Barnsley Thick coal, its thickness varying from 3 feet 4 inches to 6 feet. It has been worked only to a very limited extent, principally at Swallow Wood; and is known in Derbyshire as the Dunsil or Oldgreaves coal, lying there about 30 yards below the Top Hard seam.

The Parkgate or Thorncliffe Thick seam occurs at an average depth of 219 yards below the Swallow Wood, and has been chiefly worked at Parkgate, Thorncliffe, Pilley, &c. Its average thickness is 5 feet 6 inches, but the thickness varies considerably from 4 feet 10 inches to about 6 feet. It is known as the Bottom Soft coal in Derbyshire, where it has been very extensively worked.

The Thorncliffe Thin seam, called the Bottom Hard in Derbyshire, is found 24 yards below the preceding; its thickness is from 2 feet 6 inches to 3 feet, and it has been principally worked at Thorncliffe, Pilley, &c.

The Silkstone or Sheffield seam lies about 61 yards below the Thorncliffe Thin, and has an average thickness of about 5 feet. It is a very well defined seam, and may be taken as a sort of datum line in identifying the position of the other beds. It has been principally worked in the neighbourhood of Sheffield, and at Chapeltown, Thorncliffe, Pilley, Mortomley, and Silkstone; and is identical with the Blackshale or Clod coal of Derbyshire. The coal is of great value for house fire purposes, competing with the celebrated Hetton Wallsend.

By far the most important and valuable of the seams of coal are the Barnsley Thick and Silkstone seams. At the Woolwich trials made by the admiralty in 1851 relative to the strength and value for steam purposes of the Barnsley Thick coal from Darley Main, West Hartley coal from Newcastle, and Welsh coal from Merthyr Tydvil, the total weight of water evaporated in each case was 24,960 lbs., and the evaporation per lb. of coal was 8·10 lbs. by the Barnsley Thick and West Hartley coals, and 8·25 lbs. by the Merthyr coal. Trials were also made of the Barnsley Thick coal in 1858 at Doncaster on the Great Northern Railway, when the evaporation obtained was 7·64 lbs. of water per lb. of coal, the total weight of water evaporated being 448,281 lbs., and the coal used being a mixture of steam coal and house fire coal consumed under Cornish boilers working at a pressure of 45 lbs. The Barnsley Thick coal lights easily, burns freely, and raises steam rapidly. It produces only a very small quantity of white ashes and cinders, giving little trouble to the stokers, and the less it is disturbed the better; it does not clog or adhere to the bars, and makes no slag, maintaining a good clear fire with little sulphur. It is a most economical coal for marine engines, and in using it a light thin fire is particularly recommended.

The mines of Ironstone occur between the Barnsley Thick coal and the Silkstone coal, as shown in the vertical section, Fig. 3, Plate 21.

The first mine of importance is the Swallow Wood, about 60 yards below the Barnsley Thick coal, which has been principally worked at Milton for the supply of the furnaces there. It consists of three measures of ironstone, and an analysis of a sample of the ore by Mr. Spiller of the Geological Museum gave 26·79 as the percentage of metallic iron.

The Lidgate mine, next below the Swallow Wood, has been extensively worked at Milton, Tankersley, and Thorncliffe.

The Tankersley mine is usually found about 50 yards below the Lidgate, and is called also the Musselband ironstone from the number of fossil shells it contains. It has been worked chiefly at Tankersley, and yields about 1500 tons of ironstone per acre.

The Thorncliffe Black mine lies about 70 yards below the Tankersley: it is worked principally at Parkgate, and used in the furnaces at Milton and Elsecar; and an analysis by Mr. Spiller gave 34·16 per cent. of metallic iron.

The Thorncliffe White mine lies immediately below the Parkgate seam of coal, and consists of three measures, containing about 32 per cent. of metallic iron and yielding about 1500 tons of ore per acre. It has been worked principally at Parkgate and Thorncliffe, and was formerly worked extensively at the Holmes.

The lowest mine is the Clay Wood or Black mine, consisting of three measures, containing about 32 per cent. of iron and yielding about 1600 tons of ore per acre. It has been got to a great extent at Thorncliffe, and is identical with the Black Shale or Stripe Rake of Derbyshire, which is so much prized by the ironmasters of that county.

The principal ironworks of the South Yorkshire district are at Parkgate, Holmes, Milton, Elsecar, and Thorncliffe, in blast; and at Chapeltown and Worsborough, out of blast.

The modes of working the coal in the South Yorkshire district may be considered as modifications of the "long wall" system so extensively and successfully practised in the midland counties. The "pillar and stall" mode of working adopted in the north of England has not been much used in South Yorkshire; and the "long wall" system being principally confined to the midland counties, the South Yorkshire system of working may be regarded as a combination of the two. Where the circumstances are favourable, the "long wall" system is being extended in the Yorkshire coalfield; and wherever it can be adopted it is to be recommended on account of the simplicity of arrangement both for working and ventilation, and also as being the most economical method of getting the coal.

The principal modes of working the coal adopted in Yorkshire are the "Narrow Work," "Long Work," "Bords and Long Work," "Wide Work," and "Bank Work." These are shown in the ideal diagrams, Plates 22 to 27, the first five of which have been prepared from diagrams kindly lent for the purpose by Mr. Charles Morton, the government Inspector of mines for Yorkshire. They can be represented

only by ideal plans, because none of them are carried out in their integrity at any collieries in the South Yorkshire district; and in some instances one mode is adopted in one part of the workings and another elsewhere in the same colliery. These different systems of working, some of which however are falling into disuse, have been rendered necessary by the variable nature of the roofs and floors of the coal seams in the South Yorkshire district. The same reference letters are used throughout all the diagrams.

Fig. 5, Plate 22, is a plan of the mode of working by "Narrow Work," on the end of the coal. P is the downcast pit, and B the main "bord" (road cut transversely to the grain of the coal, against the "face" of the coal), from which pairs of "headings" or "endings" E E (roads cut against the "end" of the coal, lengthways of the grain) are driven at intervals of about 30 yards. When these endings have been carried to the requisite distance on either side of the main bord B, a communication is made between their extremities, and the coal is worked by short faces homewards, as shown at W W. The whole of the coal being thus got out, the roof is allowed to come down in the goaf as the working progresses, being temporarily kept up immediately behind the working faces by props or puncheons, which are afterwards withdrawn successively and shifted forwards. U is the upcast shaft, and F the ventilating furnace. The main current of fresh air from the downcast pit P is carried up the main bord B and along the furthest pairs of endings E, as shown by the arrows, and is then passed through the face of the workings W. The course of the air is determined by stoppings S built to block up the various crossgates between the bords and endings; and by doors D, through which the coal is brought down to the shaft from the workings W, and from the endings E that are in process of being driven. At C is an air crossing, where the current of foul air proceeding from the workings to the upcast shaft U crosses over the current of fresh air entering the mine from the downcast pit P. At R R are regulators to control the quantity of air passing through each portion of the mine; when these are closed, the whole of the fresh air has to pass through the workings before reaching the upcast shaft; but when they are opened, a portion of

the air finds a shorter course through the regulators direct to the upcast shaft, and a smaller quantity of air therefore passes through the workings. This mode of working is falling into disuse in Yorkshire, and is seldom adopted except under special circumstances, where the coal is of a soft or friable nature and where the roof is not strong, the coal being therefore got in very short lengths, as shown at W W, with only a very "narrow" face in process of working at a time, whence the name of this mode of working.

There are two modes of "Long Work," the first of which is shown in Fig. 6, Plate 23. This and all the subsequent modes of working are on the face of the coal, the workings W being carried forwards transversely to the grain of the coal, against the "face" of the coal, instead of against the "end" of the coal as in the previous "narrow work." In Fig. 6 it will be seen that there is a long face of work in progress at once in each portion of the mine: the workings are started from the main headings or endings E, and the coal from the working faces is brought down through the goaf by means of packed roads G, shown by the strong black lines, the walls of which are built up of rock and shale; the packed roads are carried forwards continuously as the working faces advance. The fresh air from the downcast shaft passes along the endings E and the packed roads G up to the working faces W, and thence by the bords B to the upcast shaft U, as shown by the arrows, the regulators R R controlling the ventilation in each portion of the workings. At H H are doors or stoppings with apertures to allow of passing some of the air through the packed roads G in the goaf, according as may be required to keep them clear of gas.

In the second mode of "Long Work," shown in Fig. 7, Plate 24, the workings are subdivided into separate lengths of face by the pillars L being left between them at first, about 30 yards thick; but when the workings have been carried forwards as far as intended, the intervening pillars are then also worked, beginning from the further end and working backwards, as seen at A, whereby the current of air is always kept up against the pillar face A until the whole pillar is removed. The packed roads G are required for bringing out the coal

through the goaf in this plan of working, the same as in the first mode of "long work;" the strong dotted lines through the goaf in the neighbourhood of the pillar working A show packed roads that are no longer required to be maintained and have been abandoned. The course of the air is shown by the arrows.

The mode of working by "Bords and Long Work" is shown in Fig. 8, Plate 25. Here pairs of bords B B are driven from the main heading or ending E, at intervals of about 20 yards; and when they have reached the extreme distance intended, the whole of the intervening coal is worked homewards, downhill, and is brought out from the working face W through the bords B. In "bords and long work" therefore the bords form a marked feature in the system, being driven to the extreme extent in the first instance, as shown in the right-hand half of the plan, Fig. 8, before the working of the whole coal is commenced; and when this has been begun, as shown in the left-hand half of the plan, no packed roads are required in the goaf for bringing out the coal from the working face, but the coal is brought down through the bords themselves, which are thus not obliterated till all the coal is won, but remain of service to the last. In the previous modes of "long work" on the contrary, shown in Figs. 6 and 7, the progress of the work is in the opposite direction, uphill, and the face of work is opened without driving bords; and accordingly packed roads are required to be maintained through the goaf for bringing down the coal from the working face. The course of the air is shown by the arrows in Fig. 8, and the air regulator is placed at R; but in "bords and long work" there is no need of any arrangement for coursing part of the air through the goaf, as is required in "long work."

In the "Wide Work" method, shown in Fig. 9, Plate 26, the coal is got in banks W about 60 yards long, each subdivided into bords 7 or 8 yards wide, separated by pillars of an average thickness of one yard, as shown by the thick black lines in the goaf. Crossgates K are made to the main roads B at suitable intervals, according to the state of the atmosphere in the mine and the ventilation. For ventilating the workings the current of air is passed up the furthest bord B, across the face of the work in the first bank W, and out at the other

end of the bank; it is then carried forwards up the intervening pillar bord B to the next bank, and across the working face in the same manner, as shown by the arrows. This method of working is now being abandoned where possible for the "long wall" system.

In the "Bank Work," shown in Fig. 10, Plate 27, the coal is got in banks W about 60 yards long, as in the last mode, but each bank is worked all in one length without any intermediate pillars being left in each bank. The method of ventilation is the same as in "wide work," as shown by the arrows. The mode of working by single bords B, as in both "bank work" and "wide work," instead of by pairs of bords, is however to be condemned on account of the difficulty and expense of maintaining packed roads through the goaf for the winning of the pillars BB at the last; or if they have not been maintained, of making new packed roads for ventilation: and again these pillars being liable to a heavy pressure, the coal in the pillar working is rendered of little value.

The plan of the "Long Wall" system of working, Fig. 11, Plate 28, shows the difference of this system from any of the ordinary Yorkshire methods of working described above. This is not an ideal plan, but a plan of the actual "long wall" workings of the Parkgate seam at the Wharncliffe Silkstone Colliery near Barnsley, Fig. 1. There is here no loss in getting out pillars, as all the coal is excavated at one operation. The ventilation of the mine is at the same time considerably simplified, the current of air having altogether a shorter and less tortuous course to follow from the downcast shafts P to the upcast U, as shown by the arrows. The thick dotted line MM shows the position of a fault in one portion of the mine, and the workings are therefore laid out at that part conformably with the course of the fault. By the "long wall" system a working face of 430 yards is here obtained in a single length without interruption, as shown at W; and in the lower portion of the workings along the fault MM another face has been opened of the same total length but divided into two shorter faces by a pillar bord, for safety and convenience of working in the neighbourhood of the fault, the intervening pillar being removed before that portion of the mine is abandoned.

Various supports for the roof are used in the Yorkshire seams: wooden props or puncheons are adopted in some cases; in others piles of wooden blocks called "chocks" or "clogs," and in others "packs" of rock and shale. Cast iron puncheons also are now being extensively introduced, one of which is shown in Figs. 17 and 18, Plate 29.

Two of the greatest difficulties that have to be contended with in mining are Water and Gas. With regard to Water, the mines in the South Yorkshire district are not in general heavily watered in comparison with other mining districts; the workings nearer the outcrops or "bassets" of the seams are generally more watered than the rest. Except in some special instances there are few collieries where large pumping engines are required: lift pumps are used exclusively, and even tubbing has scarcely ever been resorted to. A remarkable inundation occurred a year ago at the Woolley Colliery at Darton near Barnsley, Fig. 1, which is working the Barnsley Thick coal: the coal is drawn up a long inclined plane extending from the outcrop of the Barnsley Thick seam and following the dip of the seam; and the water is raised by means of flat pumps. On the 13th April 1861 a sudden irruption of water into the workings took place, to such an extent that they were almost entirely filled. The water entered through a fissure in the overlying rock, which is of considerable thickness and is full of cracks and fissures towards its outcrop. It is probable that a large amount of head or drainage water had accumulated in these fissures while they remained closed, and that they afterwards became opened by subsidence of the strata in consequence of the working of the coal: the water was found to be drawn away from a well in the rock at the surface 170 yards above the coal. The accumulation of water must have been very great, as it continued rising in the day drift a fortnight after the inundation had occurred, at the rate of more than 1 foot per hour, although a double 10 inch pump had been kept continuously at work; but its rise was subsequently stopped by additional pumping power.

In the amount of Gas generated by the different seams of coal there are great variations. The most terrible explosions have taken place in the Barnsley Thick coal, especially at the Darley Main

Colliery, the Oaks, Warren Vale, and Lundhill: the Barnsley Thick and Silkstone seams being specially liable to sudden and powerful emissions of gas. The ventilation is produced by a furnace, shown in Figs. 12 to 15, Plate 29, situated at F in the diagrams, Plates 22 to 28, at the bottom of the upcast shaft U, by which a fresh current of air is kept continuously flowing through the mine, so that any gas issuing from the coal is speedily diluted and rendered harmless. For distributing the air through the workings, the stoppings S, doors D, and regulators R are arranged in proper places. The division of the air into separate "splits," each of which ventilates a distinct portion of the workings by means of the crossings or "overcasts" C, and the "scale doors" or regulators R, may be considered, if properly carried out, one of the best preventives of explosions in these very fiery South Yorkshire mines. All the return air should be conducted into the upcast shaft by a dumb drift N, Figs. 12 to 16, so as not to pass through the fire of the furnace; and the underground furnaces, whether closed or otherwise, should be fed with nothing but fresh air direct from the downcast shaft.

At some of the mines in the district, belonging to Earl Fitzwilliam, large fans driven by steam power have been substituted for the furnace generally used elsewhere; they are a simple and efficient means of mechanical ventilation, well worth the consideration of all interested in mining, and have now been continuously working with complete success for several years. In the early periods of mining the only ventilation was the natural ventilation, the current of air through the workings being produced simply by the colder and denser air from the downcast shaft displacing the hotter and rarer atmosphere of the mine. Sometimes rarefaction was increased by putting a pan of coals in the upcast shaft; but the consequence of such imperfect ventilation was that the workings were sometimes stopped for many days together. Natural ventilation could of course be adopted only when the shafts were of moderate depth and the workings on a limited scale.

The introduction of safety lamps into mines is of comparatively recent date. In the South Yorkshire district they were first used exclusively at the Oaks Colliery, in the workings of the Barnsley

Thick coal, where Stephenson lamps are used in preference to Davys; and the use of safety lamps has since extended to many other collieries. At the Wharncliffe Silkstone Colliery near Barnsley, working the Silkstone seam, Stephenson and Davy lamps are used exclusively; and as the coalfield is very much cut up here with faults, the gas cannot be "bled" away, but as each fault is cut through the greatest caution is required in dealing with the gas in the solid coal beyond, "in bye." In addition to the use of safety lamps, an abundance of air should be taken into the working places of fiery mines. Since the explosion at Lundhill in 1857 safety lamps have been exclusively adopted there. The importance of their use in fiery workings was strongly shown at the Oaks Colliery in 1857, when an outburst of gas took place in the workings down the engine plane, so violent that it was compared to the roar of a draught in the furnace. All the Stephenson lamps were put out, and the Davy lamps were ignited internally, the gauze becoming red-hot. As the outburst of gas occurred within a hundred yards of the main intake to the upcast shaft, and a large quantity of air was passing this part at the time, the gas was soon diluted and carried away; and in less than an hour the only traces that remained were found at one or two places where the floor had been upheaved. Thus no doubt a terrible explosion had been averted by the use of safety lamps; but if any one of the lamps had been out of order, or the gauze smeared with oil or coal dust, or if any naked light had been in this part of the workings, an explosion would inevitably have occurred.

In conclusion it may be remarked that the facilities already existing by railway and canal communication for the conveyance of the minerals raised in this district to London and other markets, which in a few years will no doubt be considerably increased by the extension of the railway system,—and the central situation of the district in the great midland coalfield, the largest in England,—together with the extent to which it yet remains undeveloped,—combine to give the South Yorkshire district an important position among the mining districts of this country.

The Chairman enquired what were the principal differences in working the coal by the long wall system and by Yorkshire bank work, and what was the proportionate increase of yield per acre in long wall working.

Mr. Jeffcock replied that in the Yorkshire bank work, as shown in the diagram, Plate 27, a number of single "bords" (roads cut against the face of the coal, transversely to the grain) were driven following the rise of the coal; and at right angles to them a series of "endings" (roads driven lengthways of the grain, against the end of the coal) were cut into the intervening coal, which was then worked out, with the exception of a certain thickness left on each side of the bords to serve as pillars for supporting the roof over the bords, in order to keep them open for getting the coal out and maintaining the ventilation. The great difficulty in the bank work was in maintaining the ventilation properly up to the working faces while they were being pushed on into the solid coal beyond the last pair of endings opened, before the next ending was reached, as shown at WW on the plan; because at this time the working face was out of the direct line of the current of ventilation, and the air could not be efficiently kept close up to the workings. There was also a great loss in the quantity of coal that had to be left in the mine in the pillars; and if these were afterwards got out in a second working, the cost of working them was very great, and the coal itself was so much crushed as to be greatly deteriorated in value. But in the long wall system now being adopted, as shown in the plan of the long wall working at the Wharncliffe Colliery, Plate 28, all second working to get out pillars was avoided, the whole of the coal being worked out at one operation. The yield of coal per acre was therefore much greater in the long wall mode of working, and its value was increased by the diminution in the quantity of small coal and slack produced by the working: there was also less expense in running the few long headings required in long wall working than in driving the great number of shorter ones required in bank work. Moreover the working face was always in the line of the ventilation, without any blind recesses into which the air would not enter; and the current of air passed along the entire face of the workings throughout its whole length.

Mr. W. Mathews enquired what was the comparative cost of getting the coal by these two modes of working.

Mr. Jeffcock replied that the cost of getting would be about the same at the working faces in each case; but the total cost including "dead" charges was greater in bank work than in long wall work, on account of the expense of driving so many more passages in the former plan.

Mr. J. E. Swindell remarked that the larger amount of "dead" work on the roads in bank work must of course increase the cost of opening the mine; and the long wall system appeared much superior in requiring fewer roads for winning the coal. It was also less expensive to cut a few gate roads of large size than a great number of smaller roads. He asked what length of face was being worked on the long wall plan at the Wharncliffe Colliery shown in the diagram.

Mr. Jeffcock said the working face at that colliery was 400 yards in a continuous length, and the second face in the nearer portion of the workings was also of the same length, but subdivided by a pillar bord into two lengths: the total length of face was therefore 800 yards working on the long wall system.

Mr. J. E. Swindell supposed there would be a limit to the length of face that could be worked on the long wall plan, depending upon the quantity of coal that could be conveniently brought down the main gate roads at one time. He enquired whether the coal from the whole of the 400 yards working face was got out into the main gate roads through the single opening at each end of the face, or whether intermediate gob roads or packed roads were maintained through the goaf for conveying the coals got from the middle portion of the working face. If packed roads had to be maintained for this purpose, it would diminish the superiority of the long wall system as compared with other modes of working in respect of cost.

Mr. Jeffcock said in opening a new face of work the coal was brought out through the intermediate packed roads into the main gate road; but as the working face was carried further forwards, they were gradually abandoned and the roof allowed to fall in, their outer ends next the gate road being closed by stoppings to preserve the ventilation. To save the expense of keeping these packed roads in

repair, new top levels were driven in the solid coal at the distance beyond which the packed roads would not carry without greater expense; and the pillars were afterwards got out along the sides of the levels. At the Wharncliffe Colliery there were three main gate roads, worked as self-acting inclines, down which the whole of the coals from the two faces of work were brought to the winding shaft.

Mr. W. Mathews asked what was the inclination of the gate roads.

Mr. Jeffcock replied that they were driven according to the inclination of the coal, so as to be worked as self-acting inclines, the dip of the coal being 1 in 12.

The Chairman observed that it was very important to get as much large coal as possible, and undoubtedly more large coal could be got by a long face of work than by a short one. He enquired how far this result had been obtained at the Wharncliffe Colliery.

Mr. Jeffcock said the size of the coal got depended upon its structure, and the Parkgate seam worked at the Wharncliffe Colliery on the long wall system was of a cubical structure, easily breaking up short in working, so that the long wall system did not give so much advantage in this instance in yielding the coal large. But coal of a long fibrous character, like some of the Derbyshire coals, could be worked very large without difficulty.

Mr. J. E. Swindell asked whether the long wall system was equally applicable for soft coal as for hard.

Mr. Jeffcock replied that the long wall system was equally suitable for both, the only difference in the mode of applying it being that the hard coal was worked "on the face" (the workings being carried forwards transversely to the grain of the coal), while the soft coal was generally worked "on the end." With coal of cubical structure however it mattered little which way the coal was worked, and at the Wharncliffe Colliery the working was on the face of the coal.

Mr. J. E. Swindell enquired what was the cost of getting the coal by the long wall system.

Mr. Jeffcock replied that the cost of getting alone was about 1*s.* 5*d.* per ton, exclusive of winding power, plant, sinking the shafts, sending out or conveyance of the coal underground, and making and

maintaining the roads: but the rate of labour in South Yorkshire was nearly 15 per cent. in excess of other colliery districts.

The CHAIRMAN asked how the "deep" coal was won from the lower side of the shaft; whether a second shaft was sunk for the purpose. He supposed in laying out the colliery the pit would be planted in such a position as to win the coal as much as possible to the rise.

Mr. JEFFCOCK said the winning of the deep coal involved an underground engine for hauling it up to the pit bottom, or else the ropes must be sent down the shaft from an engine on the surface; and a flat pump worked by the engine must be put down for drainage, following the dip of the coal. But if the coal was much watered it was better to sink a second pumping shaft for draining the deep coal, and the same shaft could then be used also for winding if required.

The CHAIRMAN enquired where the flat pumps were principally used, and what was the extreme length through which they had been worked.

Mr. JEFFCOCK said the flat pumps were mainly used near the outcrop of the coal, at collieries worked by an adit, for draining workings in the deep when there was not much water. At the Woolley Colliery at Darton near Barnsley, which was worked by an adit from the outcrop of the Barnsley Thick coal following the dip of the seam, the flat pump extended a long length, from the outcrop to the furthest extremity of the workings, and was a double plunger pump with working barrels 10 inches in diameter. On occasion of the inundation at this colliery, mentioned in the paper, the second flat pump was put down for clearing the pit, the pump barrel being gradually moved forwards as the water lowered.

The CHAIRMAN asked whether the pump trees were of wood, and only the working barrel and suction nozzle of iron.

Mr. JEFFCOCK replied that the pump trees were ordinary castings, and only the spears were of wood, working upon rollers at one side of the adit: the pumps were ordinary plunger pumps delivering the water through a cast iron pipe extending to the mouth of the adit, or to a level that might be cut through the measures to intersect the adit.

Mr. W. Mathews said that at Clough Hall Colliery near Stoke-upon-Trent a flat pump was used for a distance of 100 yards following the dip of the coal at an inclination of 1 in 4 or 5, and it was about being extended to 200 yards: the pump trees and working barrel were of cast iron.

The Chairman enquired what was the weight and cost of the cast iron puncheons or props used for supporting the roof, and whether they were always managed to be got out of the mine again without loss. In some of the Staffordshire pits where they had been used, the difficulty had been to get them all out again.

Mr. Jeffcock showed a full size model of one of the cast iron puncheons, 3 feet 9 inches high, and said they were made to suit the height of the seam, weighing from ½ cwt. to 1 cwt. each, and costing from 4*s*. to 6*s*. each. They were given out to a set of men whose sole business was to attend to the fixing of them and moving them forwards as the workings advanced; and were required to be delivered up again whole or broken, otherwise the men were debited with the cost of those missing. The men were well used to the work, and generally managed to get all the puncheons out safely and without loss: on withdrawing the hindmost row of puncheons in the goaf the roof did not generally fall in immediately, but some interval elapsed before it came down, allowing time for the men to get all cleared away; in the neighbourhood of faults however there was more danger, and great caution was then needed.

Mr. J. E. Swindell asked how many of the cast iron puncheons were used in a mine.

Mr. Jeffcock said sometimes as many as 3000 or 4000 cast iron puncheons were used in a single mine, costing therefore from £800 to £1000.

The Chairman enquired whether the saving had been clearly ascertained of using cast iron props instead of wood. This was a question of great importance at the present time; for when such a large number of props were required in a single mine, the extensive adoption of iron props if found advantageous would afford an opening for the use of iron in colliery workings.

Mr. JEFFCOCK could not give the actual comparative cost of cast iron and wood props, but understood the cast iron puncheons had been found decidedly advantageous where used, and preferable to wood props. The use of cast iron however depended altogether on the nature of the roof and floor of the mine; where either of these was soft, an iron puncheon was of no use, as it would go in like a skewer.

Mr. J. MURPHY asked what was the cost of timbering the mines in the South Yorkshire district per ton of coal raised.

Mr. JEFFCOCK replied that at collieries raising a good quantity of coal the cost of timbering amounted on the average to about 1*d.* per ton of coal raised.

Mr. J. MURPHY asked whether that cost included timbering the roads. In South Wales the cost of props was generally reckoned at 3*d.* or 4*d.* per ton of coal raised, including timbering the main roads, at collieries raising 600 to 800 tons per day.

Mr. JEFFCOCK said the cost of 1*d.* per ton of coal was only for the timber props supporting the roof at the working faces, which were moved forwards after each day's work; but if the gate roads required timbering the cost would of course be much greater. Most of the packed roads however through the goaf were built up with bind or shale from the roof and not timbered.

Mr. W. P. BEALE knew of two pits working in the same seam of coal, one with wrought iron props and the other with wood, and understood the cost was decidedly in favour of the iron props. One of the pits was at Messrs. Beale's Colliery at Scholes near Chapeltown, in the Parkgate coal, where the wrought iron props had been used since the commencement of the working about eight years ago: the iron for the props was rolled of a cross section, about 4½ inches width each way and ⅝ inch thickness in the ribs (see Figs. 19 and 20, Plate 29), which was cut into the required lengths of about from 4 feet to 7 feet to form the props; a flat circular cap was then welded upon each end, and a ring shrunk on in the middle for convenience in pulling out and prizing the props. The other pit using wood props was the Newbold Colliery near Chesterfield, where the same seam was worked under the name of the Potter's coal; but the roof at the

former pit was much harder than at the other, allowing the wrought iron puncheons to be employed advantageously. Similar wrought iron props had also been used for the last ten years in Earl Fitzwilliam's pits at Elsecar and Parkgate, working the Barnsley Thick coal of about 7 feet thickness.

The CHAIRMAN enquired how much coal could be drawn per day out of one pit with the long wall system, in the Silkstone or the Parkgate seam, with a total working face of 800 yards length.

Mr. JEFFCOCK said in reference to the Silkstone seam it could not be worked in such a long face as 800 or even 400 yards, on account of the tender nature of the roof. But as regarded the general question of the quantity of coal that could be got by the long wall system, he thought the real limit must be considered to be the engine power for raising the coal; for by extending the length of working face and increasing the number of men, enough coal could always be got to employ the whole engine power available. As a case of actual working however the Oaks Colliery near Barnsley might be named, working in the Barnsley Thick coal, where 600 tons per day were now being regularly drawn by one winding engine, and sometimes as much as 800 tons per day: both shafts were used for winding, and were about 250 yards deep. It was at this colliery that safety lamps were first used exclusively in the district, the men having previously believed it impossible to work entirely with safety lamps, but this had now been done regularly ever since their first introduction there; and it was a fact worthy of notice that the large quantity of 600 to 800 tons per day was worked entirely with safety lamps, proving that the use of them did not involve any interference with the rate of working.

The CHAIRMAN enquired whether gas was employed for lighting in any of the collieries.

Mr. JEFFCOCK said it was not used in any of the collieries in the South Yorkshire district.

He explained that the paper was originally intended to be ready for the meeting at Sheffield in the previous year, in order to be read in the district to which it belonged, but he had been unexpectedly prevented from getting it ready then.

The CHAIRMAN considered the paper instead of being at all out of place in now being read and discussed in the Staffordshire district was the more acceptable, for it was only by the communication of such information from one district to another that improved modes of working could be introduced and greater economy arrived at: he was sure the information now given about the South Yorkshire coalfield would be highly appreciated in the Staffordshire district. Valuable opportunities were thus afforded by the meetings of the Institution for extending the experience of the members, and he believed advantage was always derived from the papers read and the information elicited in discussion. He proposed a vote of thanks to Mr. Jeffcock for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A FEED-PIPE CONNEXION FOR LOCOMOTIVE ENGINES.

BY MR. ALEXANDER ALLAN, OF PERTH.

Various constructions of Feed-pipe Connexion between locomotive engines and tenders have been used at different times; but the double ball-and-socket plunger pipes, made of brass, are most generally applied, in order to have a continuous metallic connexion, allowing of blowing steam through into the tender without injury. These however are very expensive, requiring great nicety of fitting and much care in their management in work; and, in consequence of sand and dirt getting in at the moveable parts, they involve a serious outlay for maintenance, and in practice it is almost impossible to keep them perfectly tight, while if the joints be too tightly screwed up there is risk of the feed-pipes breaking.

To obviate these defects and obtain a continuous metallic connexion comparatively inexpensive both in first cost and maintenance, and combining simplicity, durability, and efficiency, the writer has substituted the connexion shown in Figs. 1 and 2, Plate 30, consisting of a simple brass or copper tube A, coiled to a circle of considerable diameter, so as to have sufficient elasticity to allow for the vertical disturbance due to the unequal deflection of the engine and tender springs, and also for the extreme lateral range required in going round the sharpest curves, with a minimum strain on the joints. A solid-drawn brass tube is employed, varying from No. 17 to No. 14 wire-gauge in thickness or ·060 inch to ·085 inch, coiled to a circle of 3 feet to 3½ feet diameter, as shown in Fig. 2.

In order to offer less resistance to bending, the tubes are made elliptical in section, about 2¼ inches deep by 1½ inch broad, as shown full size in Fig. 4, Plate 31. Tubes of circular section 2 inches in

diameter, as shown full size in Fig. 5, have also been used, but they are more rigid than the elliptical tubes. Experiments have been made to ascertain the amount of force necessary to stretch and compress the coiled tube and also to deflect it vertically and laterally through the extreme range required in practice; and the results show that the elliptical tube has the advantage in elasticity, the first inch of deflection requiring only about 30 lbs. pressure, while a total pressure of from 90 to 100 lbs. is sufficient to produce the extreme deflection of about 3 inches in any direction; up to this pressure there is no permanent set and consequently no fear of the tube collapsing in any part. The experiments have been extended with the elliptical tube up to 3½ inches movement in any direction, giving a total range of 7 inches, up to which the tube may be strained safely; beyond this limit a permanent set is produced. In practice however the total range in any direction never exceeds 5 inches, or 2½ inches on each side of the central position, leaving a sufficient margin of elasticity to prevent injury to the tube. With a thinner tube or one coiled to a larger circle an increased range could be obtained if desired.

The connecting tube A is attached to both engine and tender by means of the ordinary screw and tail pipe couplings BB, Figs. 1 and 2, Plate 30, the tail pipes being brazed upon the circular ends of the tube, as shown in the section, Fig. 3, Plate 31. It is placed above the axle and suspended to the foot plate by short chains C, as shown in Fig. 1, so that the wheels can be removed without interfering with the feed-pipe connexion, and it is less liable to damage should the engine get off the rails than the ordinary ball-and-socket couplings. The connecting tube is placed central in the engine whenever practicable, so that the angular deflection produced in running round curves is reduced to the minimum; but it can be fixed without any practical objection in the usual side position of the feed-pipe, as shown in the plan, Fig. 2, so as to admit of ready application to existing engines and tenders. Figs. 1 and 2 show the connexion applied to an engine fitted with an injector D for supplying the boiler; and the dotted lines E show the end of the tube when a pump is used.

This connexion has been fitted to a number of locomotives on the Scottish Central Railway, including some large goods engines; and it has been subjected to severe tests during the last twelve months, and has given every satisfaction. In the engines on this railway the plan of coupling between the engine and tender, drawing as well as buffing on a heavy laminated spring, allows more movement than is usual, amounting to a play of 2 inches between the engine and tender, and the connecting tube is 6 inches out of the centre; but even under these conditions no failure of the connecting tube has occurred. The dimensions of the engine to which it has been longest attached are: diameter of cylinder 16 inches, stroke 20 inches, driving wheel 6 feet diameter, steam pressure in boiler 130 lbs. per square inch, and boiler supplied with one No. 9 injector; and the connecting tube has now been continuously working upon this engine for nearly twelve months with complete success, the engine having run about 20,000 miles during the time. This tube has been taken off the engine and is now exhibited to the meeting: it is of circular section and simply secured with soft solder, and there is not the slightest sign of its giving way, showing that it is fully equal to its work. A specimen is also exhibited of a connecting tube of oval section, used on large coupled engines: in its manufacture the tube is swaged oval in proper cresses, and is then filled with resin and coiled to the required circle round the cast iron blocks used for blocking tyres.

The Chairman regretted Mr. Allan had been unexpectedly prevented from being present.

Mr. Sampson Lloyd believed a somewhat similar plan of coupling had been tried on the South Western Railway, but did not know whether it had been successfully carried out on that line.

Mr. D. Joy thought the new coupling was the best connexion he had seen, and much superior to either the ball-and-socket coupling or the flexible hose pipes.

The CHAIRMAN enquired what was the cost and durability of the ordinary hose pipes.

Mr. D. JOY said the flexible hose pipes of canvas and india-rubber were the simplest connexion, and cost only about 7*s*. 6*d*. each; but their durability was very uncertain; they lasted twelve months with proper care if made of good material, but sometimes failed in a single month. He thought the coupling now shown seemed as good in simplicity and was much superior in durability; and it had an advantage in being placed close up under the foot plate, where it would be out of the way of injury if the engine got off the rails.

Mr. J. MURPHY suggested that an iron tube might be used, as cheaper than brass or copper.

Mr. D. JOY thought the extra cost of the brass or copper tube would be saved in the manufacture, from the greater ease of manipulation compared with iron, the total weight of metal being so small; an iron tube would also be more rigid, while the greater elasticity of brass or copper would increase the durability of the coupling.

The CHAIRMAN moved a vote of thanks to Mr. Allan for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

1, 2, and 3 July, 1862.

The Annual Special Meeting of the Members was held in the Lecture Theatre of the Royal Institution, Albemarle Street, London, on Tuesday, 1st July, 1862; Sir William G. Armstrong, President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Robert Angus, ...	Stoke-upon-Trent.
Henry Beckett, . . .	Wolverhampton.
Caleb Bloomer, . . .	Westbromwich.
Nelson Boyd, . . .	Hartington.
John Farmer, ...	Dudley.
Samuel Godfrey, . . .	Middlesborough.
William J. W. Heath, . .	Birmingham.
Peter Emile Huber, . .	Zurich.
Joseph Knott, ...	Leigh.
John Lloyd, . . .	Wellington, Salop.
Hugh McPherson, . . .	Gloucester.
Francis C. Miers, . .	Broadstairs.
John Millward, . . .	Stourbridge.
John R. Ravenhill, . .	London.
John Silvester, . . .	Westbromwich.
William Thompson, . .	Newcastle-on-Tyne.
Julian Horn Tolmé, . . .	London.
Richard Watkins, . .	London.
Percy G. B. Westmacott, .	Newcastle-on-Tyne.

The President then delivered the following address:—

ADDRESS OF THE PRESIDENT.

The annual meeting of the Institution in the present year occurs under circumstances of peculiar interest. The metropolis in which we are assembled has for a while become the centre of the civilised world; and the Great Exhibition which marks the period of our meeting is an event of real moment in the history of nations. This year's gathering of our Institution is therefore of a somewhat special nature; and I believe that by directing the remarks which I have again the honour to make to you from this chair chiefly to the subject of the International Exhibition of 1862, and particularly to that portion of it which comprises the works of Mechanical Engineers, I shall act most in accordance with your wishes and the spirit of the occasion. I am the more induced to do so from the circumstance that the first of these large annual meetings of the Institution was held in London during the former International Exhibition, on which occasion the late lamented Robert Stephenson was your President.

In commenting upon the present Exhibition it is impossible to abstain from some reference to its precursor of 1851. Unhappily the retrospect is a sad as well as a fitting one; for we can never forget that the chief difference between the Exhibitions of 1851 and 1862 is that over the latter there has been thrown a shade of mourning. The author of both Exhibitions saw his first work finished, and enjoyed its well earned fruits; but he has not been spared for the completion of his later task. We engineers, of all men, should lament the death of the Prince Consort, whose exalted rank never blinded him to the true dignity of labour. Though he favoured science in every branch, as well in the abstract as in its practical applications, yet he showed an evident preference for those scientific pursuits which lead to

tangible results; and we may feel sure that he would have rejoiced as heartily as any of us at the progress in mechanical engineering which is so strongly marked in the present Exhibition. Had he lived, the disparaging criticisms upon the Exhibition which have from time to time been made would probably never have been heard. If it were necessary to relieve any class of exhibitors from the false charge of mere commercial display, in no case would it be easier to do so than in that of the mechanicians. For my part I find it hard to account for the enterprise, the courage, and the self-sacrifice of the many exhibitors both from this and other countries, who, from a mere sense of the obligations imposed on them by their position in their respective callings, or from purely public spirit, have by a great effort and at a most unremunerative expenditure rendered the mechanical department in the Exhibition perhaps the most interesting and the most valuable of all. The mere association of the Prince's name and his early labours in connexion with this very Exhibition should save it from any unworthy imputations, and recall those noble principles and considerations which he has told us were the motive and origin of all international displays. Let me remind you of the words in which he first announced the objects of the former Exhibition at the banquet given by the Lord Mayor in March 1850 to the mayors of nearly every corporate town in the kingdom. "Nobody," said he on that occasion, "who has paid any attention to the particular features of our present "era will doubt for a moment that we are living at a period of most "wonderful transition, which tends rapidly to accomplish that great "end to which indeed all history points,—the realisation of the unity "of mankind: not a unity which breaks down the limits and levels "the peculiar characteristics of the different nations of the earth; "but rather a unity, the result and product of national varieties "and antagonistic qualities." "Science," he continued, "discovers "the laws of power, motion, and transformation. Industry applies "them to the raw matter which the earth yields us in abundance, but "which becomes valuable only by knowledge. Art teaches us the "immutable laws of beauty and symmetry, and gives to our "productions forms in accordance with them." "Gentlemen," he said, "the Exhibition of 1851 is to give us a true test and living

"picture of the point of development at which the whole of mankind "has arrived in this great task, and a new starting point from which "all nations will be able to direct their future exertions." Such were the Prince's words on that occasion, and they apply with equal force to the present Exhibition.

It seems to me that the most striking characteristic of International Exhibitions is that they define epochs in the continuous course of industrial progress, and render the advance attained in each period appreciable by reference to the preceding. Another attribute is that in each Exhibition the deficiencies of every contributor are brought home to himself with a force which no other means could exercise, and the strongest possible stimulus is in this way given to individual exertions. Thus in 1851 every contributor saw for the first time his own products placed side by side with those of competitors from all parts of the world, and was irresistibly made aware of his own shortcomings. The new Exhibition shows how far the contributors have understood the lessons they received ten years ago, and to what extent they have learnt and profited by them. No doubt the schooling which the English exhibitors had in 1851 was chiefly upon points of taste: yet it was not without application to subjects within the field and province of engineering, and I think we shall be ready to say that engineers have decidedly gained something from the Exhibition of 1851, and that the proof is afforded by the Exhibition of 1862.

There is one remarkable distinction between the two Exhibitions which I am peculiarly called upon to notice. Most of us may remember to have seen in the first building one or two field guns, which were generally thought to be out of place and inconsistent with the character and object of the whole display. In the present building we all know that arms and armour are predominant. Besides rifled artillery there are rifled small arms, together with armour plates and beautiful models of iron plated ships, all of which represent war, and make up a very formidable portion of the British share in the Great Exhibition. Yet this prominence of warlike material will not lead us to the conclusion that peace is endangered. The cannon may be a grim associate of peace, and yet be her best security and support.

Without it we should lie at the mercy of all the world, a tempting bait to every marauder. Our wide spread commerce and vast wealth both at home and abroad require all the protection we can give; and it is of vital importance that in guarding them we should be possessed of weapons of the highest efficiency. We may be glad therefore that the implements of war have not been excluded from the present Exhibition, more especially as they show the direction in which some of our best and most successful industrial efforts have lately been made.

Already the great struggle between guns and armour plates has proved of value even for the direct purposes of peace. It has instigated improvements in the fabrication of iron, which must prove beneficial to the productive manufactures of the country. I will instance the great exploits in rolled and forged iron achieved by the Mersey Steel and Iron Company, Messrs. Brown and Company of Sheffield, the Butterley Company, and the Coalbrook Dale Company, all having reference more or less to armour plated ships. These unusual efforts arising out of the contest between the powers of offence and defence lead the way to peaceful developments and adaptations. The armour plates have to be carried by ships of enormous strength and size. The ships involve in their construction the manufacture of rolled beams and forged cranks of dimensions and patterns such as are seen in the eastern annexe, and such as at the period of the last Exhibition would have been deemed wholly impracticable. For the propulsion of these ships marine engines are required of extraordinary power, and for their armament the skill of the mechanic is taxed to the utmost to provide guns of commensurate strength and efficiency. These efforts made in the interest of war extend the limit of our manufacturing attainments, and thus ultimately benefit the cause of peace and commerce.

In my last address I alluded to the importance of obtaining a material which should combine the toughness of wrought iron with the homogeneous character of a cast metal; and I then referred to Mr. Krupp of Essen as having taken the lead of all British manufacturers in the art of producing steel forgings of extraordinary dimensions. The specimens which Mr. Krupp has sent to the present

Exhibition justify all that I said on that occasion, and present examples which from their soundness and magnitude excite the wonder and will stimulate the rivalry of English steel makers. I fear however that it must be admitted that, notwithstanding the great advance which has been made in the manufacture of steel, we have not yet procured this material in a form which is adapted for the resistance of concussive action. All attempts to use steel for the purposes of armour plates have shown its inferiority to wrought iron; and since the qualities necessary for resisting the impact of a shot and the explosion of gunpowder seem to be identical, I am still of opinion that, whatever the future may produce, we have as yet no material equal to wrought iron for the manufacture of ordnance.

I should extend these remarks beyond suitable limits were I to attempt any detailed notice of the many interesting objects contained in the mechanical department of the Exhibition. I will therefore conclude by expressing a hope that the progress which has been made in mechanical engineering during the last ten years may suffer no diminution during the next decennial period; and if another Exhibition should arise at the end of that time, may it compare as favourably with the Exhibition of 1862 in the department of mechanical engineering as the present Exhibition compares with that of 1851.

A vote of thanks was passed to the President for his address, on the motion of Mr. C. P. Stewart seconded by Mr. C. Greaves.

The following paper was then read:—

ON SURFACE CONDENSATION IN MARINE ENGINES.

BY MR. EDWARD HUMPHRYS, OF DEPTFORD.

The subject of Surface Condensation in steam engines, especially in marine engines, was first brought to the notice of the writer in 1833 by the proceedings of Mr. Samuel Hall, then of Basford: and it is more with the view of drawing attention to the success with which this system was practised a quarter of a century ago, than of describing any new combinations possessing advantages over the plans then adopted, that this paper is submitted to the meeting; indeed nearly the whole of the practical details about to be given were published fully twenty-seven years ago.

The writer's brother, the late Mr. Francis Humphrys, was employed by Messrs. John Hall and Sons of Dartford to design the engines made by them for the paddle-wheel steamer "Wilberforce" of 280 nominal horse power; and the writer thus had the opportunity of witnessing the designing, manufacture, and working of the surface condensers fitted to these engines. Drawings of the engines are given in "Tredgold on the Steam Engine", together with indicator diagrams taken from them in 1838, one of which is shown in Fig. 15, Plate 35; and up to the present time the writer is not aware of any better vacuum having been produced. He started these engines the first time they were set in motion, in the year 1837; and has a distinct recollection of the admirable manner in which the condensers did their duty. The vessel was employed between London and Hull until 1841, when the outsides of the condenser tubes having become very thickly coated with mud from the Thames and Humber, the tubes were removed and injection was substituted.

About fourteen years ago, when the writer held the appointment of engineer-in-chief of Woolwich dockyard steam factory, he had a second opportunity of obtaining practical information as to the working

of Hall's surface condensers, from the "Grappler" which returned to Woolwich after a three years' commission abroad, having been fitted with the surface condensers by Messrs. Maudslay Sons and Field. The floats of the paddle wheels were reefed, in order to allow the engines to work at full speed at moorings, and indicator diagrams were taken which showed that the performance of the condensers was quite satisfactory, and equal to what it had been before the vessel left this country. Owing to the defective state of the hull of the ship, the engines and boilers were taken out, and the latter were found in excellent condition, indeed almost as perfect as when first put on board. The engineers reported that the condensers had given very little trouble, and on examination they were found free from any defects. These and other examples of surface condensation with which the writer had become acquainted caused him to have great confidence in the system, and to desire to introduce it again at the earliest opportunity.

In 1859, having to design and construct a set of engines of 400 nominal horse power for the Peninsular and Oriental Co.'s new ship "Mooltan", with the view of trying what economy could be effected in the working of the machinery of their vessels, the writer determined to employ surface condensation, not expecting to realise any large amount of economy from this system alone, but believing that a great benefit would result from the increased durability of the boilers, and the saving of the time frequently lost in cleaning them, together with some economy of fuel arising from the absence of the necessity of blowing out. The practice of blowing out is indeed frequently carried to excess: in one instance known to the writer, at least four times the quantity of water necessary to keep the boilers clean was blown out, the expenditure of fuel being consequently most excessive.

Figs. 1 and 2, Plates 32 and 33, show very nearly the arrangement of the condensers of the "Mooltan"; and they show correctly the condensers now making by the writer for the Peninsular and Oriental Co.'s new ships "Mysore" and "Rangoon" of 400 nominal horse power. The area of surface in the condensers and in the boilers of all the three ships is almost identical: the boilers contain 4800 square

feet of heating surface in each ship, and the condensers of the "Mysore" and "Rangoon" contain 4712 square feet of condensing surface, and those of the "Mooltan" 4200 square feet. The indicated power of the "Mooltan" when tried officially was 1734 horse power; hence the area of condensing surface per indicated horse power is rather less than 2½ square feet.

For convenience of manufacture and arrangement of these engines, the condenser of each is divided into two parts AA, Fig. 1, Plate 32, each part being exhausted by its own air pump B, Fig. 2, Plate 33, so that each pair of engines is provided with four air pumps and four condensers. The air-pump B is 18 inches diameter with a stroke of 3 feet. These dimensions being used by the writer with injection condensers in engines of the same nominal power, he believes they are larger than necessary for surface condensers of engines in good condition, with condensing water at the average temperature of the sea in this climate; but as these engines are to be employed in the Indian seas, it was considered expedient to provide large air pumps and large pumps for circulating the condensing water, so as to allow of almost any quantity of condensing water being driven through the condensers that may be found necessary in an Indian climate. The air pumps B discharge their water direct into the boilers through the pipe C, according to Hall's plan, so that no feed pumps are necessary. The air which leaks into the engines is allowed to escape by an open stand-pipe connected to the highest point of the feed pipe, and carried up inside the mast, which is of iron, to a greater height than is due to the pressure of steam in the boilers. A valve regulated by a float was originally fitted to the "Mooltan" for allowing the escape of the air; but it was found to require some little attention, and hence the stand-pipe was substituted which answers perfectly without any attention.

Each condenser AA, Figs. 1 and 2, contains 1178 seamless drawn pure copper tubes, ⅝ inch outside diameter and No. 18 wire-gauge or ·050 inch thick, 5 feet 10 inches long, weighing 28 oz. each tube, and fixed at 1 inch pitch centre to centre, as shown full size in Figs. 3 and 4, Plate 34. The tube plates of the "Mooltan" are of cast gun-metal ⅞ inch thick; but those of the "Mysore" and

"Rangoon" are of rolled copper, finished $\frac{3}{4}$ inch thick, one of which is exhibited. These are first set as flat as possible, and the tube holes marked out upon them. The holes are then drilled under a common drilling machine with a drill of two diameters, shown half full size in Figs. 7 and 8, Plate 34, having a guard D upon it to fix the depth to which the larger diameter shall penetrate the plate. One machine worked by an ordinary driller drilled the 1178 holes in the tube plate exhibited in 70 hours. The tapping of the holes is then proceeded with, and is effected with a tap, shown half full size in Figs. 9 and 10, having a parallel end E to guide it, which fits the smaller diameter of the tube holes. One man of ordinary skill tapped the 1178 holes in the plate exhibited in 70 hours. After having been drilled and tapped the tube plate is again set perfectly flat on a surface plate, and then both sides are faced off in a lathe or planing machine.

The screwed glands FF, Fig. 3, Plate 34, for securing the packing at the ends of the tubes, are made from Muntz' metal solid-rolled tubes, which are obtained in lengths of about 5 feet, rolled to gauge both inside and outside; the inside diameter is exactly that of the outside of the copper tubes, namely $\frac{5}{8}$ inch, and the outside diameter is such that when screwed it will exactly fit the tapped holes in the tube plates. It is screwed on the outside as it comes from the maker in a common screwing machine, as shown full size in Figs. 5 and 6, and is then cut by a circular saw into half inch lengths to form the glands. The saw marks are taken off the ends by a facing cutter revolving in a lathe, shown half full size in Figs. 11 and 12, and the same operation clears out the inside of the hole. The notch for the screwdriver is cut by passing a number of the glands, when screwed into a plate, under a revolving circular saw of the required thickness. The packing is composed of linen tape; a piece of this tape 12 inches long and $\frac{7}{16}$ inch wide is wound round a mandril, the ends and edges being slightly stitched, in which state it is readily put into the tapped holes of the tube plate, and when screwed down by the gland forms a very perfect and lasting joint. The thickness of the tape is such that 1000 of these packings weigh about 2 lbs.

The exhaust steam from the engines passes down through the interior of the condenser tubes, and the sea water for keeping the tubes

cold is driven up through the spaces between the tubes. The sea water is admitted through an inlet pipe fitted with a slide valve at the bottom of the ship, and enters the condensers at the bottom by the pipe G, Fig. 1, Plate 32: it then circulates round the outsides of the tubes, and makes its exit through the regulating valves HH at the top of the condensers, at about the load water line of the vessel. The valves HH answer the purpose of regulating the flow of sea water equally through the two divisions AA of the condenser, and also of shutting out the water from above when the outsides of the condenser tubes have to be examined. The flow of water is produced by one of Appold's centrifugal pumps, the diameter of the revolving disc being 36 inches; it is driven by a pair of wood and iron spur wheels, the proportions of which are about 1 to 3½, so that at the ordinary speed of the engines of the "Mooltan", namely 56 revolutions, the pump makes 194 revolutions per minute. Two of these pumps are provided, the second being driven by an auxiliary engine to be used in case of the failure of the other.

The condensers constructed according to the proportions and mode of manufacture above described and adopted by the writer have been found quite efficient and very durable. The indicator diagrams, Figs. 13 and 14, Plate 35, taken from the "Mooltan" in a voyage in October of last year, show the degree of exhaustion in the cylinders, which are 96 inches diameter and 3 feet stroke, the steam being exhausted into them from the high pressure cylinders of 43 inches diameter and the same length of stroke: the boiler pressure was 17 lbs. per square inch. The engines were making 58 revolutions per minute, and the diagrams show that the vacuum in the cylinders was sufficient to support a column of mercury 26 inches high when the vacuum in the condensers was 28 inches of mercury.

The condensers of the "Mooltan" have now run 42,000 miles: and at the end of 30,000 miles, namely in April last, the writer examined the inside and outside of the condenser tubes, and found the outsides perfectly clean; but inside there appeared a slight coating of grease resulting from the lubricating material employed in the interior of the engines. This was however so slight as not to affect the action

of the condensers; indeed the vessel ran the last 300 miles of the 30,000 at an average speed of 60 revolutions per minute with 24 lbs. steam in the boilers, and the vacuum in the condensers supporting a column of mercury 27½ inches high. A very careful examination of the inside of the boilers showed that the action of the surface condensers, returning always pure water into them, is likely to ensure their continued efficiency, as there was no appearance of deterioration whatever. The lubricating material employed in the engines collects in the boilers, adhering to the sides and stays about the water line, and is to be found in large lumps in the bottom water space below the furnaces: this requires to be taken out occasionally, otherwise in the opinion of the engineer in charge it causes the boilers to prime.

Before determining on adopting exactly Hall's mode of manufacture for the condensers, although his experience of it had been very favourable, the writer examined the other plans for surface condensation, in most of which the joints between the tubes and tube plates are made with vulcanised india-rubber; but having understood that a chemical action took place between the copper of the tubes and the sulphur employed in preparing the india-rubber, and not being able to discover in the new plans any advantage over Hall's condenser, he adhered to this construction in the condensers of the "Mooltan." As regards the action of the vulcanised india-rubber on the copper tubes, the writer placed a piece of copper tube inside a piece of vulcanised india-rubber tube, and carefully washed and weighed the copper tube every month, and found a gradual decrease in its weight.

In designing the engines of the "Mooltan" no provision was made for cleaning either the insides or the outsides of the tubes of the condensers, except that the connexion between the condensers and cylinders was so arranged as to admit of the ready removal of the entire condenser case with its tubes. Each condenser case is a rectangular vessel about 2 feet 10 inches by 3 feet 6 inches and 5 feet 10 inches high, as shown in Figs. 1 and 2, Plates 32 and 33; and by removing the bolts in the joints I and K at top and bottom the entire condenser with its tubes can be drawn out clear of the cylinder, and the inside of the tubes can then be cleaned, the tube plates being in this case of gun-metal cast with the edge thickened ½ inch

all round on the outer face, so as to clear the projecting glands of the tube ends. The two condensers of one engine might be removed, the tubes cleaned, and the condensers refixed in 40 hours; but up to the present time there is nothing in the state of the condensers to indicate the necessity of cleaning either the insides or outsides of the tubes; indeed the outsides are cleaner and brighter than when the tubes were first fixed in their place. When it becomes necessary to clean the insides, it is recommended to apply a solution of caustic soda by filling the condenser with it up to the top of the upper joint I; this was also the practice followed by Hall with success in his condensers in 1837. Indeed Hall's condensers were employed in the "Penelope" for more than six years, and the engineer in charge during that period stated that, with the exception of occasionally cleaning out the insides of the tubes by the application of a solution of soda and water, the condensers never gave an hour's trouble. The cost of a sufficient quantity of the solution to clean out the condensers of a 400 horse power engine would be about £5; and it is possible that it may be found desirable to perform this operation once a year.

The loss of water that occurs in the boilers from leakage and other causes is made good by an auxiliary boiler, the steam from which is passed through a small engine which pumps the water for supplying the hydraulic apparatus employed in steering the ship and other purposes, whereby the coal consumed in the auxiliary boiler is utilised.

Mr. Humphrys showed some of the solid-drawn copper tubes used in the condensers, and one of the copper tube plates containing 1178 holes at 1 inch pitch, drilled and tapped; also specimens of the screwed glands and tape packings, and of the tools used in making the holes of the tube plate, as described in the paper.

He remarked that the whole condenser was of simple construction, the metal tube for making the glands being obtained rolled to size, so that it required only screwing in a common screwing machine, and

then cutting into half inch lengths to form the glands. By screwing down the gland sufficiently, the end of the copper tube was even indented slightly all round by the pressure of the packing, as seen in the tube exhibited, so that the ends of the tube could be really fixed in this way: in practice however one end of the tube was left free, to allow of expansion and contraction. The condenser was made essentially the same as it had been made twenty-five years ago by Mr. Hall, and he believed was a very perfect apparatus. In the condensers he was now making, the outsides of the tubes could be washed through pretty readily, as the centrifugal pump employed to drive the cold water through the condenser could also be made to work like a bilge pump for drawing the bilge water out of the ship; and by then taking off the cover of the side hole at the bottom of the condenser a considerable current of water could be sent through, so that if any dirt should accumulate at the bottom, in consequence of the condenser having been employed in dirty water, it would be all removed by the rapid current of water. Up to April last however, when the "Mooltan" had run 30,000 miles, no dirt had accumulated in the condensers.

The Chairman enquired the reason of the failure of former attempts with Hall's condenser, and why it had gone out of use.

Mr. Humphrys did not consider there had been any failure in the former trials of Hall's condenser, but believed it had been really successful from the time when first tried thirty years ago. The great prejudice however at the time against any change from injection condensers had prevented the use of this surface condenser being persevered in; and objections had been raised to its use which the present experience had now fully proved were not attributable to the principle of the condenser.

Mr. J. F. Spencer observed that he had also been working for many years at surface condensation, but on the opposite system of pumping the cold water through the interior of the condenser tubes and condensing the steam on the outside; and he was glad now to learn the practical results of the working of Hall's condenser in a large ship, as described in the paper, the merits of that condenser having certainly not been fully appreciated. He thought they were

much indebted to Mr. Humphrys for having brought forward the subject, and for the valuable record of facts contained in the paper that had been read.

In making a comparison between the two plans of surface condensers—the one with the condensing water outside the tubes and the steam inside, and the other with the steam outside and the water passing through the inside of the tubes—it was not necessary to consider either the space occupied by the condenser or the mode of making the joints at the ends of the tubes: because the space occupied depended entirely on the size of tube employed, and the same size might be adopted whether the water passed through the tubes or whether it passed outside; and the manner of making the joints by means of packings and screwed glands, as described in the paper, which was certainly a clever construction, might be adopted for any plan of condenser. Setting these considerations aside therefore, he considered an important practical difference between the two systems lay in the circumstance that in order to examine a single tube of a condenser on the construction shown in the drawings, with the water outside the tubes, it was necessary to break a vacuum joint; and if such a joint were made again defectively at sea in a hurry, air would leak in, the vacuum in the condenser would be diminished, and the efficiency of working impaired. Whereas when the water was inside the tubes, all the ends of the tubes were accessible by simply breaking a water joint, which was a matter of little consequence; for if this joint were made defectively at sea, the only result would be a small outward leak of water out of the condenser, which would not affect the working of the engines in the slightest degree. In this respect therefore he thought a real practical advantage attended the plan of passing the water through the inside of the tubes.

A better distribution of the water through the condenser was also obtained by the same plan of passing it through the tubes instead of outside. In the condenser shown in the drawings, with the water outside the tubes, he thought it would be almost impossible to pass the water thoroughly and equally over every portion of the condensing surface; whereas with the water inside the tubes, by dividing the whole quantity of water into three or four currents distributed equally

throughout the condenser, and by proportioning the area of the tubes to that of the pump, the water might be driven over every portion of the condensing surface with almost complete uniformity. This he considered a very important point, and attributed to it much of the condensing power possessed by condensers having the water inside the tubes, with which he had obtained a condensation of 12 lbs. of water per hour per square foot of condensing surface, which he believed would be found greatly in excess of the general result. For judging of the efficiency of a condenser, the main point to be ascertained was the weight of water condensed per square foot of condensing surface per hour, in order to know how much heat had been abstracted from the steam per square foot of surface, without any regard to either the nominal or the indicated horse power of the engine; and the condensation of 12 lbs. of water per square foot of surface per hour was the result he had obtained in work actually done in the "Sentinel," a vessel fitted with one of his surface condensers having the water inside the tubes, and working on the east coast of England. He enquired what was the amount of condensation per hour per square foot of condensing surface in the "Mooltan."

Two vessels of 400 nominal horse power had now been working nearly two years in the Canadian mail service between Liverpool and Quebec, the "Hibernian" and the "Norwegian," which he had fitted with the surface condensers having the water inside the tubes; and they made the voyage to Quebec and back, indicating 1200 horse power, on a consumption in one voyage of 32 tons of coal per day. In this case however the expansion was very limited, and there were circumstances which prevented the economy from being carried out as would be wished; and in two other similar boats of 400 nominal horse power now building for the same line he hoped a better opportunity would be obtained for showing the advantages of surface condensers.

With reference to the use of vulcanised india-rubber for making the joints at the ends of the tubes, and its effect on the copper tubes, he had now upwards of 50,000 of these joints working, a great many of which had been working for several years; and out of that number there had been but three cases of deterioration of the copper tube

from the action of the india-rubber, and in each of these cases the deterioration arose simply from defective fitting. Where there was a stream of hot salt water passing between the india-rubber and the copper tube, there corrosive action took place; but that was the result of defective workmanship. In all the rest of these joints, not a single case of the kind had occurred. He had lately had some of the tubes removed that had been working in condensers sixteen or eighteen months, and there was not the slightest appearance of deterioration. It was important to have so complete an answer to any objection on that score, because india-rubber was a very convenient material to use for any kind of joint, adapting itself by its elasticity to almost all conditions.

Mr. F. J. Bramwell enquired what was the degree of vacuum in the condenser at the time when the condensation of 12 lbs. of water per square foot of surface per hour was being obtained; because the amount of condensation varied with the vacuum that had to be maintained. He enquired also what was the proportion between the condensing surface and the boiler surface.

Mr. J. F. Spencer replied that in the "Sentinel" which he had referred to, of 100 nominal and 350 indicated horse power, the vacuum in the condenser was 25 inches of mercury at the time of condensing 12 lbs. of water per square foot of surface per hour. The boiler surface was 1750 square feet, and the condensing surface 850 square feet, or practically one half of the boiler surface, which was the proportion he had generally adopted, giving in this case 2½ square feet of condensing surface and 5 square feet of boiler surface per indicated horse power. Sometimes he had employed rather less condensing surface; but in no case had he made it exceed 3 square feet per indicated horse power, reckoning the boiler surface at about 6 square feet per indicated horse power or about 22 square feet per nominal horse power. In the "Hibernian" and "Norwegian" the boiler surface was 6200 square feet and the condensing surface 2700 square feet, being 5¼ and 2¼ square feet respectively per indicated horse power.

With regard to the accumulation of grease in the condenser, that was one of the reasons why he preferred the plan of having the steam

outside the tubes; for he believed it would be found that a condenser with the steam outside the tubes would last three times as long, with the same accumulation of grease, as one with the steam inside the tubes. It was evident that the accumulation would take place much more rapidly inside the tubes, and that the speed of passage of the steam would be much more retarded with each additional layer. He had had one condenser working about three years without any cleaning at all, the tubes being horizontal with the steam outside, and found that three fourths of the condenser was perfectly free from grease, and the remainder had only a small portion on the upper side of the tubes, the lower side being perfectly clean. A practical conclusion however could not be drawn from one or two cases; for at the first starting of a new plan great care was taken to obtain a satisfactory result, by using no more grease in the engine than was absolutely necessary for lubrication; but when a large number of condensers were at work, they would be subject to the usual casualties and want of attention at sea: grease might accumulate in the boilers and condensers, and would accumulate more rapidly he thought in Hall's condenser than in condensers with the steam outside the tubes.

The Chairman observed that the proportion between the boiler surface and the condensing surface that had just been described was as two to one; whereas the areas in the case given in the paper were 4800 square feet of heating surface and 4712 square feet of condensing surface, or practically the same.

Mr. Humphrys said it must be borne in mind that in this case the 4800 square feet of heating surface in the boilers gave only 12 square feet per nominal horse power or 2¾ square feet per indicated horse power, instead of 6 square feet of boiler surface per indicated horse power as had been mentioned; and a comparison could not be made between different cases without taking into account the proportion of boiler surface per horse power. As regarded the quantity of water condensed per square foot of condensing surface, no experiments had been made; but the proportion of the condensing surface to the indicated horse power was 2½ square feet per indicated horse power.

In reference to examining and cleaning the condenser tubes, this could be done in the condensers of the "Mysore" and "Rangoon" by taking off the manhole doors shown in the drawing immediately below the condenser. There was a height of 6 feet from the underside of the lower tube plate to the bottom of the water chamber, allowing room to stand upright inside, below the condenser, and with a rod the whole of the tubes could then be sponged out in a short time. A similar manhole door in the steam chamber above the condenser allowed of getting in to make good any tube joints at the top that might fail. He had however found the joints made as described in the paper remain good already for six years with ordinary brazed tubes: the tubes in the condensers of the "Mysore" and "Rangoon" were solid-drawn tubes, like the specimen exhibited, with which the joints could be made steam-tight with still greater certainty.

The CHAIRMAN asked whether any wear of the tubes had been observed, or any corrosive action.

Mr. HUMPHRYS replied that he had not found any wear or corrosion of the tubes whatever, and the condensers had not given the slightest trouble in any way. The cost of the tape packings for the tubes was very small and they were obtained at 16*s*. per thousand, ready coiled for putting in their places on the ends of the tubes.

Mr. T. HAWKSLEY was glad to find that the great merits of Hall's surface condenser were so fully acknowledged in the paper that had been read; he was intimate with Mr. Hall at the time of this invention, and thought it was much to be regretted that the inventor, after making a large fortune by other inventions, had been ruined almost entirely by this particular one. His surface condenser was introduced in only a few instances, and in each case had been removed again after being some time at work. The construction was exactly as had been described in the paper; and the reason why the condenser was objected to was for the most part that the tubes were found to clog with grease, so that the condensation became slow; and although the means were simple enough for cleaning the tubes, by employing some alkaline solution that would combine with and remove the grease, yet nothing of that kind being then attempted the

condensers did not act efficiently, and on that account were abandoned. In the next place the boilers accumulated oil, and the oil became decomposed into a thick gluey or tarry substance, which after being kept for some time in the boilers became like a piece of india-rubber, and got into a semi-elastic state: this substance settled down upon the plates and kept the water off the surface, so that the plates were burnt. Moreover the oil, before it had become decomposed, searched out every little defect of rivetting and closing of seams, and caused corrosion to take place at that part, so that boilers which had not leaked before began now to leak. These effects were attributed to the introduction of the surface condensers, rather than to defective workmanship; and the condensers themselves were accordingly removed. The coating of the tubes with grease and the effect upon the boilers of the introduction of grease into them were the only two objections that could be raised against the system of surface condensation, and he believed they could be removed by the use of an alkaline solution as had been described.

In respect of the proportion of the condensing surface to the horse power of the engine, Mr. Hall used 2800 square inches or nearly 20 square feet of condensing surface per nominal horse power, a much larger proportion of surface than had now been mentioned. When the tubes were clean and that proportion of condensing surface was used, the vacuum was formed very quickly; but when a smaller surface was used and the tubes became at all foul, then the condensation, although at the end of the stroke very perfect, was much smaller at the commencement, so that the mean vacuum formed during the whole of the stroke was much less than by the ordinary process of water injection.

Mr. G. A. Everitt remembered Mr. Hall's endeavouring nearly twenty years ago to obtain solid-drawn copper tubes for his condensers; and thought the failure of the condenser might be partly due to the want of solid-drawn tubes, like that now exhibited, which were not made at that time.

Mr. Humphrys did not think the failure of the early condensers could be attributed to the want of solid-drawn tubes, because the tubes in the present condensers in the "Mooltan" were like those used by

Mr. Hall, brazed tubes such as could be got thirty years ago, and similar to the tubes used in the condensers of the "Wilberforce" by Mr. Francis Humphrys twenty-seven years ago.

Mr. G. A. Everitt remarked that brazed tubes were made better at the present time than twenty or thirty years ago. He enquired how long the condensers in the "Mooltan" had been in use.

Mr. Humphrys replied that the condensers in the "Mooltan" had now been in use nearly two years, and had proved perfectly successful, without any leak in either the tubes themselves or the stuffing-boxes at the ends of the tubes.

As regarded the proportion of condensing surface used by Mr. Hall, the condensers in the "Wilberforce" had about 14½ square feet of condensing surface per nominal horse power, and the engines worked at about double the nominal power, so that the actual condensing surface was 7¼ square feet per indicated horse power, whilst in the "Mooltan" it was only 2½ square feet per indicated horse power. The difference however was explained by reference to the indicator diagrams (Figs. 13 to 15, Plate 35), from which it was seen that in the "Wilberforce" (Fig. 15) a cylinder full of steam at atmospheric pressure was thrown into the condenser at each stroke; whereas in the "Mooltan" (Figs. 13 and 14) the steam was let out into the condenser at only 2 or 3 lbs. above the condenser vacuum, requiring consequently a much smaller proportionate amount of surface for condensation to maintain the same degree of vacuum.

Mr. T. Hawksley could confirm the proportion just mentioned of the condensing surface per indicated horse power in the "Wilberforce", having understood from Mr. Hall that he generally adopted the proportion of not less than 6 square feet of condensing surface per indicated horse power, the steam being at that time exhausted into the condenser usually at about atmospheric pressure.

Mr. F. J. Bramwell regretted that the question of nominal and indicated horse power was mixed up in the consideration of the condensers; and thought the comparison should be made upon the basis of the weight of water condensed per square foot of condensing surface per hour, having regard to the vacuum at which it was condensed. A few years ago he had made some experiments on

surface condensation, in conjunction with Mr. Cowper, which were conducted with great care: the steam was passed through a horizontal tube immersed in an open trough of water, and the weight of water condensed was ascertained, with the weight of the water passed through the trough to condense it; the amount of heat put into the condensing water was also observed, and the loss due to radiation was allowed for. It was found that with a stream of water entering the trough at the end at which the condensed steam left the tube, when the steam entering the tube was maintained at exactly atmospheric pressure, 37⅛ lbs. of steam per hour were condensed and brought down to a temperature of 107° Fahr. by every square foot of external surface of the tube, the stream of condensing water entering the trough at 41° and leaving it at 100° at the end at which the steam entered the tube.

Mr. Humphrys observed that in the condenser described in the paper the condensing water driven in through the inlet pipe at the bottom caused a continual rush of cold water over the surface of the tubes; and as the water became heated it would immediately rise to the top of the condenser and be discharged through the outlet valves. If any increase of temperature were found to take place in either division of the condenser, the regulating outlet valves afforded the means of turning a greater current of the condensing water through that division; and in ordinary working the current of water was equally divided between the two portions of the condenser by the regulating valves. By thus keeping a constant and uniform flow of cold water over the surface of the tubes the proportion of condensing surface was reduced to 2½ square feet per indicated horse power, which he believed was as small a proportion as any surface condensers were working with.

The Chairman enquired whether the efficiency of the condensation was found to increase very much with the quantity of cold water driven through the condensers.

Mr. Humphrys replied that he had just received the account of an experiment which had now been tried on that point with the condensers of the "Mooltan." In crossing the bay of Biscay the temperature of the sea rose gradually from 58° to 70° Fahr.: and at the higher temperature the vacuum in the condenser of the forward engine was

26¾ inches of mercury, and in that of the after engine 26½ inches. The discharge valves of the condenser of the after engine were then closed, so as to allow the whole of the condensing water driven by the centrifugal pump to pass through the other condenser, and the vacuum in the forward condenser was thereby raised to 27⅛ inches; that is it rose ⅜ inch when the quantity of water passing through the condenser was doubled. Practically therefore no difference was produced in the condensation by increasing the quantity of condensing water beyond that employed for maintaining the vacuum in ordinary working.

Mr. E. A. Cowper could confirm what had been stated by Mr. Bramwell as to the experiments that they had tried on surface condensation: the experiments being made with the tube placed in an open trough, all the changes that took place could readily be observed. The first change that took place in the appearance of the tube was that it began to look as though it had a bloom on it, a sort of foggy or misty appearance, which was attributed to the air in the water coming in close contact with the tube and remaining there. This was wiped off, but soon returned again, and after a time small bubbles of air began to be formed on the surface of the tube, increasing in size from 1-32nd inch diameter up to as much as about 3-16ths inch, when the bubbles began gradually to leave the tube and float up through the water. But before this took place, one half of the tube surface was enclosed in air, in a sort of air jacket, which effectually kept the water from close contact with that part of the tube. After the air bubbles had been brushed off, they began to collect again, and in a few minutes the same effect was produced; so that in regular working he was satisfied that with horizontal tubes one half of the surface was non-effective when the water was at rest, the non-conducting layer of air keeping the water from the tubes. The horizontal position of tubes in condensers he therefore thought was erroneous in principle, whether the water were outside or inside the tubes. In the experiments the steam was inside and the water outside, whereby there was less obstruction to the air in rising from the horizontal tube than when the water was inside; for it was evident that if the water was inside, unless there was a great rush of water the air would remain in

the tube, and the upper part of the tube might be thoroughly coated with air. He thought it was preferable in practice to put the condenser tubes vertical, with the water inside them; and believed that a strong current of water up through the tubes in the direction in which the air bubbles would naturally rise would be very efficient in brushing them off. It might even be worth while to put a spiral brush inside each of the tubes in the condenser, which would not seriously obstruct the passage of water through the tubes, and might occasionally be moved up and down a few inches in order to remove the air bubbles. It was clear that a large portion of the surface of the tubes was covered with air; and this ought to be borne in mind in constructing any condenser, whether the tubes were vertical or horizontal, or the water inside or outside.

The Chairman enquired whether the effect of a strong current of water in removing the air bubbles from the surface of the tubes had been ascertained.

Mr. E. A. Cowper replied that he had tried experiments to ascertain the effect of a current, and found that a strong current of water, equal to 10 feet head, running freely, brought the air bubbles off pretty well: 3 feet head of water brushed a few of them off, that is all that were as much as 1-8th inch diameter; but if there was no current, they would increase to the size of 3-16ths inch diameter before quitting the surface of the tube. But he had not been able to get any current strong enough to take the bloom of minute air bubbles off the tube, and considered this could be done only by direct mechanical means. He thought therefore the tubes ought to be vertical, with the water passing up through the inside of them, as the sectional area of passage inside the tubes was less than that outside, so that the velocity of the current of water would be greater over the surface. Moreover in a forest of tubes, as in the condenser shown in the drawings, there was a difficulty in getting any strong current of water into the middle of that forest, unless there were openings or gangways purposely left amongst the tubes for it to pass in. No doubt the condenser described in the paper was a very efficient one; the only question was whether it could not be made still more efficient.

In reference to the durability of the tubes used in the condensers, some of the brazed tubes used by Mr. Hall certainly did split and leak, though many of them answered their purpose very well: but it was undoubtedly a great advantage in the construction of surface condensers at the present time to be able to obtain such sound tubes as the solid-drawn copper tubes now exhibited.

The action of grease in the boilers when surface condensers were used appeared not to have been generally understood: copper boilers were very common just before the introduction of Hall's surface condenser, but as soon as it was applied iron boilers were used, which were found to suffer considerably from little holes being eaten into the plates inside; and it was supposed that small particles of copper from the condenser tubes were carried over into the boiler with the distilled water, and that a sort of galvanic battery was formed which produced the small holes in the boiler plates. He believed however that this was a mistaken idea, and that the effect was not produced by galvanic action, but more probably arose from the grease and tallow used to lubricate the engine becoming decomposed by the constant action of steam or hot water. If any ordinary fat, such as tallow or the common oils having a neutral base, were boiled in water or submitted to the action of steam for a long time, a fat acid was formed; and the fat acids were very actively corrosive, particularly on iron. Hence the grease settling on the sides of the boiler, and becoming an active fat acid, would eat into the iron plates just like sulphuric or any other acid, dissolving the metal chemically; and he believed this was the sole cause of the boilers being damaged when surface condensers were used.

Mr. G. H. Bovill observed that it was of importance to have some information as to the actual amount of difference in efficiency between vertical and horizontal tubes for condensing. He remembered that some years ago, when experiments were made with Du Tremblay's surface condenser, it was found that there was a great advantage in having horizontal tubes in the condenser; and in the case of several large surface condensers for sugar works, put up by Mr. Pontifex, in which the tubes were horizontal and the condensing

water was supplied in a sort of shower bath on the outside of the tubes, a much better result was obtained with the horizontal tubes.

With reference to the failure of Hall's condenser, he believed a great deal was due, as had been suggested, to the defective make of the brazed tubes. At the time when the experiments described by Mr. Bramwell and Mr. Cowper were made, which were conducted for the purpose of Du Tremblay's condenser, it was considered advisable to test every tube, as it was of great importance to get good sound tubes. Each tube was tested under water with a considerable pressure of air, so that the slightest leakage was detected by the air bubbles rising; and when thus tested the percentage of leaky tubes was very large, although they had appeared perfectly sound under steam proof; therefore, although the tubes in Hall's condensers might have appeared sound, unless they were put to some such severe test they might have failed in working. Moreover in the engines where Hall's condenser was formerly applied the pistons had the old hemp packing, and great quantities of tallow were accordingly used. Now however the surface condensers had certainly a better chance of success than ever previously, and he thought much better results might be expected with the present improved constructions. He enquired how the expansion of the tubes had been found to act upon the joints at the ends of the tubes in the condensers of the "Mooltan."

Mr. Humphrys explained that every tube was perfectly free to expand by means of the stuffing-box at each end; but by screwing down the gland tighter at one end the tube was practically made a fixture at that end, being still free at the other end, and no trouble whatever had been experienced with the joints.

Mr. W. Richardson enquired what means could be employed to prevent the injurious effect of grease upon the boiler plates when a surface condenser was used, from its lodging upon the plates over the fire and allowing them to get hot, and also from its corrosive action upon the plates.

Mr. E. A. Cowper replied that a simple plan for preventing the grease from acting in any way upon the boiler plates was to give it something else to act upon, by placing a lump of chalk or some similar base in the boiler, which neutralised the acid; a solid insoluble

soap was thus formed in the boiler, nearly as hard as chalk, which remained unchanged in the water for any length of time. He had seen large lumps of this neutralised grease taken out from a boiler, which had done no harm to the plates and caused no trouble; they either floated on the surface or went down to the bottom in solid lumps, and no priming was occasioned by their presence in the boiler. In ordinary boilers without surface condensation, the grease was carried away with the water; but with surface condensers returning constantly the same water to the boiler, the strength of the acid grease was continually augmented, and it became necessary to add the neutralising base purposely, to prevent injurious action on the plates, unless there was sufficient impurity in the water that was added to make up for waste.

Surface-evaporative condensers with horizontal tubes and the steam inside the tubes, having water trickling outside to keep them wet, as had been alluded to, had been made by Mr. Perkins with iron tubes 1½ inch diameter, double the diameter of the copper tubes exhibited. In that plan of condenser it was necessary to have the tubes horizontal, because if they were placed vertically it would evidently be very difficult to keep them wet from the top to the bottom, and this indeed could be done only by a perfect shower of water; whereas when they were horizontal they could be kept wet with a very little water. This plan of condenser with horizontal copper tubes had long been used by sugar-boilers for evaporating the saccharine solution. He had put up several surface-evaporative condensers made by Mr. Perkins for steam engines, and they answered admirably.

Mr. T. Hawksley mentioned that Mr. Hall made an excellent glass model of the condenser with glass tubes, in order to observe the difference of action with horizontal and vertical tubes, the steam being inside the tubes in both cases. When the tubes were horizontal, the steam being let in at one end, the other end of the tubes was filled with water; and on the steam being let in, the water was observed to be blown forwards 6 or 8 inches, and afterwards returned again gradually along the tubes, so that they were in fact never clear of water. When the tubes were vertical, and the steam admitted at the

top, they were of course always empty. With the horizontal tubes however the condensed water inside the tubes became very cold and the steam appeared to be rapidly condensed by contact with it; so that there was no observable difference in the time occupied by condensation, whether the tubes were horizontal or vertical.

The Chairman remarked that there must be an analogy between surface condensers and boilers with horizontal and with vertical tubes; and it was known that in boilers with vertical tubes the production of steam was less rapid, owing to the lodgment of air upon the outside of the tubes. He suggested that it might be practicable to combine the advantages of both forms of condenser by causing the current of condensing water to be driven across the tubes; in which case, so far as lodgment of air on the tubes was concerned, precisely the same cooling effect would be produced as in the horizontal arrangement, while at the same time the tubes would be perfectly drained by their vertical position. In the condenser shown in the drawings the current of water appeared to be an ascending one, parallel with the tubes instead of across them.

Mr. T. Hawksley said the plan of driving the current of condensing water across the tubes had also been tried by Mr. Hall, but no advantage was found to be derived from it.

Mr. J. F. Spencer remarked that, in reference to the prevention of corrosion in the boilers when surface condensers were used, he had had two or three serious cases of corrosion in boilers, and in each case it had been stopped by the simple plan of making a change in the water supplied to the boilers, which he believed was the best remedy. Whether the corrosion arose from the acid of the grease, or from the presence of copper, or from whatever cause, it might easily be removed by shutting off the auxiliary boiler and supplying a small quantity of salt water, so as to make a complete change in the water during a given period of time. In the steamers of the Canadian line a serious corrosive action had been found to be going on in many parts of the boilers, which was completely stopped by this means, and no such action had taken place since.

Mr. E. A. Cowper had heard of a vessel fitted with surface condensers, which made a few voyages to America and back, and

the boilers were nearly destroyed by the corrosion, having been supplied with distilled water from the first. In a sister vessel however the boilers were filled with salt water in the first instance, and then the supply was kept up with distilled water, and they were not found to corrode.

Mr. J. F. Spencer said that was the case he had referred to, and both the ships were fitted with surface condensers in the same way: the first ship ran three voyages to America and back before the corrosive action was noticed; but in the second ship the corrosion was checked almost as soon as it had commenced.

Mr. G. H. Bovill enquired whether the boilers in these American vessels were new boilers, or old boilers to which new surface condensers had been applied. If they were new boilers he could understand that by admitting a certain quantity of salt water to give a kind of encrusted surface to the plates the corrosive action upon them would be prevented.

Mr. J. F. Spencer replied that the boilers were quite new in both cases. In another vessel that had now been running for about five years, the boiler had been worked with surface condensers from the first, but the water had always been changed from the commencement at regular intervals; in this instance the boiler was still very nearly in its primitive condition, and scarcely deteriorated at all, and the boiler tubes had lasted 4½ years, which was about the usual average.

Mr. Humphrys said that, as to the deterioration of boilers when surface condensers were used, the experience in the "Mooltan" had been most satisfactory; the boilers were as perfect now, after the vessel had run 42,000 miles, as when they were started; there was no appearance whatever of any corrosive action in them, though no precautions whatever had been taken to prevent it. In the case of the "Grappler", he had carefully examined the insides of the boilers after they had been at sea on the coast of Africa for three years, and no corrosion had taken place; and also in the boilers of the "Penelope" there had been no corrosion after six years' work: both these vessels having Hall's condensers. He was at a loss to account for the corrosion stated to have occurred in the other instances that had been mentioned, where surface condensers had been used.

Mr. G. H. Bovill enquired whether the waste of water from the boilers in the "Mooltan" was made up with salt water or distilled water; and also whether the boiler tubes were made of different metal in these boilers and in those which had suffered from corrosion.

Mr. Humphrys replied that the waste of water in the boilers was made up with distilled water in the "Mooltan", as well as in the other cases that he had named; there were no tubes in the boilers, which were constructed on the plan of a series of alternate flat flues and water spaces, and were entirely of iron.

Mr. J. F. Spencer said the tubes in the boilers he had spoken of were iron tubes; but the corrosion was not confined to the tubes, but acted equally on the plates of the boilers.

Mr. T. Hawksley remarked that in the land engines to which Mr. Hall applied his surface condensers no corrosive action was observed in the boilers, which were iron boilers of an ordinary kind.

The Chairman understood superheating of the steam had been adopted in the "Mooltan", and enquired whether the peculiarly successful results of the surface condensers, more especially as regarded the preservation of the boilers, could be ascribed in any way to that circumstance. He asked also what amount of saving was effected by superheating the steam.

Mr. Humphrys replied that the engines of the "Mooltan" were working with superheated steam, but he did not consider that this could bear at all upon the prevention of corrosion in the boilers. The amount of saving effected by the superheating in this case he had not been able to ascertain accurately, having had no means of analysing the results to learn the proportion due to superheating. The readiest method was to take the indicated horse power of the engines as the basis of comparison; and with this standard he was satisfied that a considerable saving of fuel was effected by superheating in comparison with other vessels using ordinary steam, having obtained an economy averaging from 15 to 30 per cent. with superheated steam. Such an amount of saving was of great importance when it was considered that some companies were now paying as much as £800,000 per year for coals. At the time of fitting the "Ceylon" with engines 2½ years ago he put in a superheater made of sheet iron with plates ¼ inch

thick; and three months ago the plates were found to be nearly cut away with the rush of steam, having been in work 2½ years. The saving effected was so satisfactory, amounting to about 22 per cent., that the iron superheater had now been replaced by one of copper weighing 10 tons.

The CHAIRMAN enquired what amount of superheating was given to the steam.

Mr. HUMPHRYS replied that the steam was heated to about 310° or 320° Fahr., and sometimes as much as 350°, the object being to give about 100° of superheating, though 80° was found sufficient in practice for obtaining good results. He did not think the superheating could be carried to a greater extent without causing trouble with the rubbing surfaces by evaporating the lubricating material.

The CHAIRMAN asked whether the present successful use of the surface condensers could be ascribed to the use of a smaller quantity of grease in the engines than formerly.

Mr. HUMPHRYS thought the success of the surface condensers was mainly due to that cause, as very little grease was used in the engines fitted with the surface condensers. A pipe open to the water space of the boilers was attached to the top of each cylinder, so that if the engine began to "sing out" for want of lubrication a small jet of water was turned on into the cylinder, to prevent its being too dry: there was also the means of supplying oil, but the main resource was water, which satisfactorily answered the purpose.

The CHAIRMAN remarked that all engineers must agree in feeling themselves under an obligation to Mr. Hall who originally proposed the system of surface condensation, though he did not succeed in bringing it fully to maturity; and they were much indebted to Mr. Humphrys for now bringing forward this interesting and important subject, having succeeded in reviving a valuable invention which had fallen into abeyance for so long a time. It might be remarked in connexion with the surface condenser that the solid-drawn copper tube now exhibited afforded an example of how progress in one manufacture administered facilities to other branches of engineering; for it was clear that the brazed tube, however it had

succeeded in the condensers described in the paper, was by no means equal to the solid-drawn tube; and undoubtedly the introduction of the latter would be a great advantage in perfecting the system of surface condensation.

He proposed a vote of thanks to Mr. Humphrys for his paper, which was passed.

The following paper was then read :—

ON THE APPLICATION OF THE COPYING PRINCIPLE IN THE MANUFACTURE AND RIFLING OF GUNS.

By Mr. JOHN ANDERSON, of Woolwich.

At the Newcastle Meeting of this Institution in 1858 the writer gave a paper on some applications of the Copying or Transfer principle in the production of wooden articles. The object of the present paper is to give a continuation of the same subject with reference to productions in metal, more especially in connexion with the manufacture of rifled guns or similar structures.

The leading feature in all modern contrivances for producing a definite form of precise dimensions is the introduction of the required form into the apparatus in various ways, by means of sliding rests, rolls, or dies, and under many other modifications; the machinery being arranged generally in such a manner that the required form may be transferred to the article under operation without being dependent upon any particular skill of the attendant workman, beyond that minute acquaintance with the principles of the cutting or working of the metal and the best formation of the cutting instrument or other details, upon which so much depends as regards both quality of produce and cost of manufacture. In looking back to the early days of the turning lathe, before the introduction of the transfer principle in the sliding rest, it is interesting to observe that even then the lathe was a perfect instrument so far as it was a copying machine; those common lathes that were made with a perfectly round spindle neck, if any such existed, would yield a round figure in the article under operation, providing that the cutting instrument was held steadily. And even in a still higher degree was correct workmanship attained in the old-fashioned dead centre lathes; if the centre holes in the article to be turned were formed with moderate care and the article held steadily between the centres, then

the surface developed by the cutting instrument when firmly held would be as perfect a circle as one described by a pair of compasses.

With such apparatus however the chances of error were numerous, arising principally from the spindle necks not being perfectly round; for even in the case of modern lathes a perfect spindle neck is more rarely obtained than is generally supposed, as a close examination will show, the polygonal form being much more predominant than the true circle. There are lathes, even among those of the most recent make, which have only to be handled gently to show their condition in this respect. Until recently such approximations to roundness were sufficient; but the extensive introduction of the Whitworth gauges into workshops has, besides teaching the importance of precise dimensions, made engineers familiar with true circles. Hence there is now a much greater appreciation of positive truth of workmanship, where truth is important; and in well conducted workshops there is a constant striving after that condition and a gradual closing up of every avenue whereby error can creep in.

Such extreme accuracy is sometimes thought to be more costly than a less careful system; but the writer has arrived at a contrary opinion, and is convinced from observation in other workshops as well as in that under his own superintendence that while extreme accuracy may be more expensive at the outset, especially from the want of workmen competent to carry it out, yet with a little perseverance the advantage arising from it will be clearly perceived and the apparently inordinate cost will shortly be brought below that of less perfect arrangements. Many articles after being carefully turned and planed have to undergo a long course of filing and scraping before they are brought to the required quality of surface; whereas if a small fraction of this outlay were spent in making the copy in the lathe spindle or the copy in the plane perfect as patterns, the great expense of subsequent fitting would be avoided. Many examples bearing on this point could be given were it required: an illustration may be named that came under the writer's experience in the manufacture of guns at Woolwich Gun Factory. Certain rings about a foot in diameter had to be fitted on corresponding cylinders, and were required to be perfectly easy to move, yet without

shake, as any looseness in the fit rendered them useless; they had therefore to fit approximately like the Whitworth gauges. Several good new lathes were tried in vain; endless scraping and grinding had to be resorted to. Still the writer was convinced that if the source of roundness were positively round, the result ought not to be out of truth. Measures were accordingly adopted to obtain perfection of roundness and steadiness in the lathe, at little more than the cost of fitting one of the rings; and the subsequent cost of the rings was thereby reduced from the value of nearly three days' work to less than an hour's. The lathe spindle became a true copy, the sliding rest a correct medium of transfer, and the combination of the two yielded the required truth and roundness. A similar case occurred in the manufacture of a number of large fire cocks: the sockets and plugs were carefully turned, but they would not resist the water pressure without a great deal of scraping and grinding, until the lathe spindle was positively brought to perfect roundness, when the turning alone made them fit with scarcely any grinding. The lathe is a copying machine, and just as its bearing surfaces are so is the work produced.

In preparing the successive layers of tubes or cylinders for building up the Armstrong gun, it is absolutely essential that strict attention should be paid to the truth and concentricity of the several parts, in order to obtain a bearing of the whole surface; more especially as the work approaches completion is it necessary to ensure truth and correct surfaces. With the view therefore of securing these results without being entirely dependent on the men who attend to the turning lathes or even on the accuracy of the lathes themselves when they are old and not very reliable, and with the view also of preventing the quality of the work from degenerating when attention is withdrawn from this part of the manufacture, the writer has adopted the methods about to be described, by which the object is attained with simple arrangements for transferring the original and carefully prepared true roundness to the successive portions of the guns; and although containing no new contrivance, still a description of the particular arrangements adopted may be interesting.

As before observed, although a perfect circle might be expected to be obtained from a dead centre, the actual result depends on the condition of the centres. The centre point may be polygonal, even though to the eye it appears round; and if the centre hole is carelessly made with a common drill, the chances are many that it is not round. Hence under such circumstances the work turned will not be true, but will be in form some combination of the two surfaces by which it has been produced: but if both these are round, the work turned will be truly round also. The rough cylinders or tubes for the guns as they arrive from the forge are first fitted with temporary centres, and are then turned on a dead centre; after which the temporary centres are removed, the turned part of one end of the tube is pushed into a chuck and the other end is placed in a bearing. The true surface which is obtained from the dead centre becomes the copy and form for the after opening of a portion of the interior by a slide rest; this interior portion then becomes the guide for a half-round boring bit, which again in its turn is the instrument to transfer the copy of the round hole onwards, although in an imperfect manner when strictly examined. A repetition of the process by another opening and a second boring bit still further improves the bore; but even still when carefully measured it is imperfect, although ready for being turned on the outside. Previous however to the turning being performed on the outside of this first or inner tube, a second or outer tube is treated and bored in a similar manner, but still more carefully; and with this outer tube an attempt is made at correct dimensions in the bore. After boring, it passes to a measuring department to have any line of roughness on the surface of the bore removed: the correct dimensions are carefully taken at every twelve inches to three places of decimals by means of a vernier instrument, and all the dimensions are recorded on a slip of paper, together with the respective amounts of contraction to be given. The latter are always represented by a decimal in the third place, amounting to one, two, or three thousandths of an inch; differing according to the part where it is deemed most advantageous to make the first seizure, and gradually diminishing towards the muzzle end in order that there may be freedom for the longitudinal contraction.

It may be useful here to direct the attention of engineers to the use of the vernier for fine measurement. In the Royal Gun Factories it is the familiar instrument for measuring, and now that its value is known it is surprising that it should be so little employed except for mathematical instruments; for by its use the thousandth part of an inch is as easily read off as larger dimensions. Some of the most recent machine tools are graduated only with thick coarse lines, by which it is impossible to set or adjust the machine with any degree of accuracy except by a process of trial and error. If these machines had a vernier, the error could be reduced a hundredfold without the use of a microscope, merely by having the standards of the machine graduated in inches subdivided into 10ths, with a vernier of 99-10ths of an inch (or 9·9 inches length) placed on the horizontal slide which has to be adjusted, the vernier being again subdivided into 100 equal parts, each of which would consequently be 1-1000th of an inch less than the 1-10th inch divisions of the main scale; by this means the dimensions would be read off by eye to 1000ths of an inch, without having to observe divisions finer than 1-10th of an inch.

By means of the vernier the exact dimensions of the bore in the outer tube of the gun are obtained. These dimensions are rarely if ever what they were intended to be, although the true dimensions are aimed at in boring; but any one attempting to make a correct Whitworth gauge even on a small scale will find out how difficult the task is. Even in some such gauges that are made by other makers it is only necessary to try the plug from both sides of the gauge to see at once that the pretension to accuracy is a mere delusion. As it would be very expensive therefore to obtain fixed dimensions in a long tube, and since moreover in a structure to be built up they are not necessary, provided the actual dimensions are correctly known from the vernier, the bored tube is taken as it comes from the boring machine with all its imperfections, often amounting to 5-1000ths of an inch; the precise dimensions, together with the small addition for the contraction to be given, are recorded on a slip of paper; and along with this slip of dimensions a bundle of corresponding steel gauges carefully marked with ink are sent to the

workman who is to turn the outside of the inner tube ready for insertion into the outer tube. The gauges are marked with ink because the dimensions are too minute to be maintained, and the gauges are never used twice without being verified; that is they return again to the measuring department of the works, and are again written upon with ink for the next tube on which they are to be employed.

For turning the tube a lathe with a round spindle is employed, and one end of the tube is pushed upon a projecting plug on the end of the spindle; the plug is the driver, and is made slightly conical so as to adapt itself to any variation of diameter in the bore. Into the other end of the tube a mandril is inserted by pressure, leaving a foot of projection which constitutes the bearing of the tube at that end, the shifting headstock of the lathe being used merely to touch the extremity of the mandril with a flat centre. Thus one end of the tube receives the truth or error of the lathe spindle, and the other end receives the truth or error of the mandril, the middle being a compromise between the two. In cases where the lathe spindle is imperfect or doubtful, a mandril in a bearing is used at both ends of the tube, thus rendering truth independent of the lathe. The mandrils are kept of sizes differing by one thousandth of an inch, and are carefully made in regard to their truth and roundness. The turning of the tube proceeds in the usual manner until the gauges fit at the several points, and after a little experience a good and attentive turner has no difficulty in working to one thousandth of an inch, provided that care has been employed in making the gauges all of one weight, because the fit is entirely a matter of refined touch and any difference in weight misleads the hand. The many inaccuracies in the diameter of the bore of the outer tube arise from the wearing of the cutting instrument and possibly from a difference in the quality of the metal: they may amount to 5-1000ths or even 10-1000ths of an inch or more. Still by careful gauging the precise dimensions are ascertained, and the fit becomes as good as if the inordinate trouble of making the bore perfectly parallel had been gone into.

When the turning of the inner tube is completed, it is taken with the paper slip and the gauges to the measuring department, and is

carefully gauged by the vernier; and if found correct it passes to the shrinking department, where the outer bored tube, having been heated to a dull red heat is shrunk securely upon it. Every part of the outer tube is then under the proper amount of tension, and a misfit never occurs, since any error in turning the inner tube is detected in the measuring department. If a tube is found to have been turned down too small, it is detained until a corresponding outer tube of smaller bore comes forward, to which it is then adjusted.

In preparing the shorter cylinders which form the outer parts of the gun, all preliminary turning is dispensed with: the rough cylinder is at once held firmly by end pressure in a vertical boring machine, and a strong boring bar with a number of cutters is set to work, which quickly finds its way through; this is repeated a second time and a sufficiently good bore is produced. In this bore the truth is dependent on the circularity of the boring bar, which works in a bearing at one end, the other end being fitted and held in the driving spindle of the machine. The bore is never perfect in size, although correct dimensions are aimed at; it may be one hundredth of an inch or more over or under the proper size, and is generally tapered in consequence of the wearing of the cutters. But such errors are not any disadvantage, since all are detected in the measuring; and corresponding gauges with a paper of dimensions are sent to the turning shop. Thus a proper and correct fit is secured without the expense of attaining perfection in the diameter and parallelism of the bore. In this manner the whole structure is under a previously determined amount of tension, and each layer of cylinders is in the condition for performing its full amount of duty in the gun.

On close observation it is found that the grip of every additional cylinder shrunk on affects the interior of the gun in proportion to its diameter and thickness; hence any careful workmanship bestowed upon boring the innermost tube at an early stage would have been thrown away. The formation of the bore therefore now commences, and it should be perfect in the strictest sense of that word; but such accuracy is attained with only variable success even when the most refined appliances are employed. It is not so much that any one bore

cannot be made perfect, but the difficulty is to ensure that the bore shall be continuously right in a succession of guns, at a small cost and without any special attention on the part of the workmen. The assertion that comparatively few holes of any great length are either of the required size or parallel or even round may not meet with general acceptance; but such is the writer's opinion at the present time, and it is founded on the difficulty which he has himself experienced in securing any one of these conditions. Unless true roundness exists in the copy from which the form is derived, there can be no roundness in the work; and unless a standard of the correct size exists in the instrument, there can be no real attainment of correct dimensions with a cutting tool which is constantly wearing. These are self-evident truths; and the nearer the approach to that point where the maximum of truth and parallelism and the minimum of expense may be said to meet together, the more completely is an important desideratum accomplished in the manufacturing economies of the engineering workshop. By extremely slow cutting and by resorting to grinding, approximations can be made to accuracy; but such a system is slow and expensive and incompatible with economical manufacture on a large scale. Hence other means have to be employed, when accuracy is dependent on the tools and the system, rather than upon the workmen who use them.

In the manufacture of guns, more especially of rifled cannon, one great object is to have the bore of definite dimensions, perfectly straight and parallel. The difficulty of accomplishing this depends entirely on what is considered straightness or parallelism, and on the closeness of measurement which may be adopted. With reference to dimensions: if the bore were completed in its boring up to the exact size previous to rifling, it would, from the rubbing of the rifling block and the rusting and cleaning after proof, be considerably over the size when actually finished. Hence it is found necessary to bore only up to within 2-1000ths of an inch of the proper dimensions, and two plug gauges are employed for the purpose, one 2-1000ths of an inch under the proper size and the other exactly the proper size; the first is 12 inches long and must pass through the bore like the plug in the Whitworth gauge, while the other should not enter. In working

so near, there is of course much liability of exceeding the dimensions; hence the entrance for the final boring tool is made from the muzzle end where an enlargement is of the least consequence. In the preparation of instruments for such precise boring it is found in practice that adjustable cutters are the most economical and convenient, with packings of the finest paper, which may now be obtained less than one thousandth of an inch in thickness. But in every instance these tools wear to some extent before reaching the other end, even if there is nothing left for the last cutter in the series to cut away. The further end of the bore is therefore smaller than the other to an extent which is never less than one thousandth of an inch; but this difference is not considered sufficient to warrant the risk that would be incurred in proceeding from the other end a second time with a newly adjusted instrument still untried. In dealing with muzzle-loading guns, the difficulty is much increased in comparison with breech-loading, as the latter afford great facility of arrangement; and it is to breech-loading guns that the present paper chiefly refers.

In order to prepare for the last boring but one, the original bore of the innermost tube becomes the basis to work from, on the same plan as already described with reference to the previous preparation of this tube for building up the gun. It has lost its truth to some extent by the shrinking on of the exterior tubes, but that is recovered by future steps. A true bearing is then turned upon the exterior of the gun at both ends, and it is placed in bearings on a long saddle in a vertical machine. A boring bar with several sets of cutters is used, which works in bearings at both ends of the gun, and has upon it a block that follows the last set of cutting instruments. The bar revolves in fixed bearings, the gun having a slow motion upwards. There is usually about 2-10ths of an inch in the diameter to be cut out by this preliminary operation, and the aim is to continue the bore up to the required size, namely 2-1000ths of an inch below the finished dimension, but this is seldom done; care is taken however that the bore is not above the size. It might be supposed that the turned bar and bored bearings would give a round hole, but this is not the case unless they are perfectly round themselves; hence these portions of the machine are looked upon as a foundation of truth,

and are prepared as carefully as if intended for gauges. The boring bars, although made of steel like the gauges, are constantly wearing and require vigilant attention to keep them up to truth. The hole from this boring is generally nearly straight, but never parallel; hence it is difficult to examine it with gauges, although no other mode of measurement is of any value in giving precise information on so delicate a point.

The next and last boring is done with the intention of making the hole parallel, but with no effort at straightness except what is derived from the bore itself as already made. The tool employed is a long broaching bar, shown in Fig. 7, Plate 39, with six cutters AA arranged in two sets of three each, as shown enlarged in Figs. 9 and 10. The first three cutters have all the work to do, the second set on entering being adjusted to the same diameter and intended only to scrape any of the surface that may be left from the first, which is not much, as there is seldom more than one thousandth of an inch altogether to be cut away. Both sets of cutters cut on the side rather than the front. The value of three cutters for steady cutting is well known; but it is also found that such an instrument is very apt to make a bad polygonal bore unless it copies a true circular form from something else. This true circular form, in addition to straightness of bore, is taken from the bore itself as already made. The transfer is effected by means of the bearing surfaces BB on the broaching block, Fig. 9, which are long spiral surfaces made of gun-metal and filling the bore. In the earlier instruments it was found that straight bearing surfaces on the broaching block were liable to allow the roundness of the bore to wander into a polygonal shape; but by twisting the bearing surfaces into a spiral form round the block, as shown at B B in Fig. 9, this liability has been prevented. An ordinary horizontal lathe is the most convenient for this operation, but it is found difficult to keep the bore sufficiently clear from the cuttings; hence the lathes are placed at a considerable inclination, to allow a stream of soapy water to flow through.

The bore is now within one thousandth of an inch of being parallel, but is never positively correct, though considered sufficiently

so in the present stage of the manufacture. All the tool adjustments for these precise dimensions are performed with great strictness by a special department; still with all the care that can be employed it is found extremely difficult to obtain at once the required conditions of correct size and roundness, with a straight and parallel bore. The gun thus bored, when examined and passed by the measuring department, is ready for the operation of rifling. Without this special department for measuring, the quality of the gun would speedily degenerate and tell unfavourably on the smooth cutting of the grooves in the rifling, since the rifling block is entirely dependent on the bore for its parallelism and steadiness.

The foregoing mode of boring applies to guns that are open at the breech; but in the case of muzzle-loading guns that are closed at the breech the approximation to a perfect bore is obtained by boring entirely from the muzzle and employing extreme care in opening with a slide rest; and then by having nicely fitted bearings behind the cutters so as to transfer the truth of the muzzle onwards, which is accomplished to a certain extent successfully, but not so perfectly as by the former arrangements. Much more skill in the workman is required to produce a perfect bore; indeed it is rare to find a bore which may be pronounced nearly perfect in the strict sense of the word; and any want of that high condition tells severely on the future operation of rifling, when the fitting of the rifling block in the bore is dependent on the parallelism of the bore for its steadiness and smoothness of cutting.

The manner of cutting the interior grooves for rifling the gun is independent of the different descriptions of rifling; and in any plan of rifling, with proper arrangements for transfer from copies, the most recondite descriptions of grooves can be formed inside the gun as easily as straight lines on the exterior.

In 1845, some guns being suddenly required to be rifled, an ordinary planing machine was extemporised for the purpose, and the required spiral was cut on the rifling bar, as shown in Figs. 8 and 13, Plate 39, which was left free to revolve in a bearing. The nut for the rifling bar to work through was attached to the muzzle of the

gun; and the machine being set in motion, its reciprocating action effected the cutting of the spiral rifle groove, and an ordinary dividing plate gave the requisite number of grooves. Such a combination possessed all the elements for rifling guns with a simple spiral that was parallel at the sides and on the bottom; but in practice guns have to be rifled with a continually varying twist, with a varying width of groove, with sudden turns, with the shape of one side of the groove continually altering in form, and with many other peculiarities; and hence such simple arrangements will not suffice for their production, and other combinations have to be resorted to.

During the last few years an extraordinary amount of attention has been directed to the subject of rifled guns; and as most of the inventions have been carried out in the Royal Gun Factory, it has been necessary to provide for executing any description of grooving without having recourse to an elaborate copy for each in the immediate instrument, which is expensive and usually involves the loss of considerable time in getting the gun ready for trial. At the same time it may be stated that the simple square bar cut in a spiral or twisted form, as shown in Figs. 8 and 13, Plate 39, when it can be employed, is the most perfect rifling instrument, because there can be no error in using it, which is not the case when the twist of the grooves is dependent on the adjustment of a machine that is ready to perform any description of grooving. In the construction of permanent rifling bars it is now found that a round bar with a spiral groove cut in it answers the purpose almost as well as the square bar cut into a spiral or twisted form, as shown in Figs. 8 and 13, the spiral groove in the round bar and also the spiral twist in the square bar being both cut in an ordinary screw-cutting lathe. Such bars however cannot readily be applied where the spiral is of increasing pitch, where there are sudden curves, where the grooves shunt, or indeed for any groove which is not a true portion of a screw.

In a rifling machine intended for irregular grooving it is necessary that there should be facilities for cutting any form of twisted groove, first as regards the sides of the spiral, and secondly as regards the

bottom of the groove; and the two requirements must be so combined that all the cutting may be done at the same time.

Such a machine is shown in Plates 36, 37, and 38, which represent the rifling machine employed in the Woolwich Gun Factory. Fig. 1, Plate 36, is a general side elevation of the machine, and Fig. 2 a general plan. Figs. 3 and 4, Plate 37, are transverse sections to a larger scale, and Fig. 5 an enlarged side elevation of the traversing saddle which carries the rifling bar. Fig. 6, Plate 38, is a combined diagram illustrating the principal motions, the tangent bar I which gives the twisting motion to the rifling bar being here represented in the vertical plane, in order that it may be seen in combination with the copy bar O which gives the feed motion to the cutter in the rifling head: the lengths are also shortened in some of the dimensions for convenience of illustration, but the side elevation and plan, Figs. 1 and 2, show the correct dimensions and relative positions of the various portions of the machine.

The rifling bar C, Figs. 1 and 6, is round and parallel, one end being held firmly in a bearing D on the traversing saddle E, with a number of collars to take the pull of the cutter; while the other end is free to turn and slide in a stationary bearing F near the muzzle of the gun G. The longitudinal motion of the rifling bar may be given by any of the planing machine motions; that by the screw H, Fig. 2, is preferred on account of the smooth action which it affords. The twisting motion of the rifling bar is derived from the tangent bar I by means of the rack J sliding transversely on the traversing saddle E and gearing into a pinion on the end of the rifling bar C, Figs. 4 and 5. The tangent bar I can be set at any angle by means of the adjusting screw and graduated arc, or can be made of any shape within the limits that the machine is capable of following the quirks of the rifling. Hence to produce any description of twisting in the grooves of the gun it is only necessary to employ a tangent bar of suitable pattern for the purpose, which will be faithfully copied on the interior of the bore by means of the rack J tracing the pattern. In guns where there are several twists or alterations of form in a single groove it is sometimes necessary to have several differently shaped tangent bars piled one on the top of the other, each of which

is used in turn by adjusting the tracing rack J to the bar to be copied; and in this way any form however recondite can be accomplished as easily as a regular spiral.

In the greater number of rifled guns the depth of the grooves is uniform, but in others it is a varying surface at different positions of the bore; hence it is necessary to have the cutting instrument arranged so as to vary in depth as it proceeds along the gun. It is also of importance that the cutter should not rub on the gun as it returns, since the rubbing affects the maintenance of a fine cutting edge on the tool, and smoothness of cutting is an essential condition. It is therefore necessary that the cutting tool shall be in a slide rest or holder in the head of the rifling bar, and capable of being drawn out or in transversely as required. For this purpose the rifling bar C is made hollow, and the tool holder in the rifling head K, Fig. 6, is actuated by an inclined slot L in the internal feed rod M, as shown in the enlarged sections of the rifling head, Figs. 14 and 15, Plate 39. By working the feed rod M longitudinally out or in, a radial motion is given to the cutting tool in either direction. The feed rod M projects from the other end of the hollow rifling bar C, and its longitudinal movement is governed by the roller N which traces the copy bar O, Fig. 6; the form of the copy bar O is thus transferred by the lever to the feed rod M, and hence any indentations on the bar O are given to the bottom of the groove in the gun. To prevent the cutting edge of the tool from rubbing in its return, an upper rail P is provided, having a trap R and S to open and close at each end in order to allow the tracing roller N to pass. The drawings represent the machine in the forward traverse, in the act of cutting a groove in the gun, the arrows showing the direction of the motion. During this time the roller N is tracing the copy bar O; but on arriving at the end of the bar the roller lifts open the trap R, as shown dotted in Fig. 6; and when it has passed the trap, the latter immediately falls and forms an incline for the roller to run up in its return course backwards and ride upon the upper rail P, thus pushing the feed rod M inwards in the rifling bar C and thereby withdrawing the cutting tool, which remains withdrawn during the

whole of the return traverse of the machine. When the roller N reaches the other end, it finds the trap S open by means of the balance weight; but the roller folds the trap downwards, as shown dotted in Fig. 6, thus forming a bridge to enable it to pass over. The trap is then opened again by the balance weight, and on starting again in the forward motion the roller drops down the incline T at the commencement of the copy bar O, thus drawing out the feed rod M and thereby advancing the cutter into its working position. The incline T gives the form to the entrance of the groove in the gun, and is generally of very definite shape. It will thus be seen that any description of feed motion can be given to the cutting tool; and hence by means of the tangent bar I and the copy bar O any kind of rifling can be accomplished without difficulty. To illustrate the capability of the machinery, a specimen rifled tube has been made (shown in the International Exhibition) with grooves cut in four different ways, one of which is spiral and wavy, undulating on the bottom, and having the width of the groove formed with a progressive irregularity.

For the purpose of advancing the cutter after each traverse so as to obtain the additional depth required in the next cut, the outer end of the feed rod M has a screw and hand wheel U upon it, Fig. 6, Plate 38, by which the cutter is set up to cut deeper in each successive traverse, until the groove is finished to the required depth. The hand wheel also affords the means of taking up the wear of the cutter, so that all the grooves are finished to exactly the same depth. When one groove is completed, the gun is turned forwards through the required arc by means of the ratchet wheel V upon the muzzle, Fig. 3, Plate 37, which serves as a dividing plate, being made with the same number of teeth as there are to be grooves in the bore of the gun.

Experiments have recently been made with another kind of cutting instrument, by which the whole of the grooves are made at one time by means of a circular rifling head carrying as many cutters as there are grooves to be made. A series of these rifling heads are used in succession, following one behind another on the same bar, each one cutting the groove a little deeper than the preceding one, and by

pulling through ten or twelve of them the grooving is effected. This kind of instrument is applicable only to breech-loaders, but so far as economy is concerned it is the most expeditious of all methods. In some of the rifling tools made on the former plan of withdrawing the cutters in returning, eight cutters have been used; but it is doubtful whether they are more economical than a smaller number, as time is lost in obtaining perfect adjustment with so many cutters working to one thousandth of an inch. Where no variation is required in the depth of the grooves, a rifling head with fixed cutters can be used, as shown in Figs. 11 and 12, Plate 39. The cutters are here fixed in a block rocking upon a centre pin in the rifling head, to allow them to clear in the return traverse, as in a planing machine: they are set up after each traverse by an adjusting screw in the rifling head, advancing the block in which the cutters are fixed. This rifling head is for cutting the grooves in muzzle-loading guns, the cutters being set to cut inwards from the muzzle towards the breech as the rifling head is pushed down the gun, instead of in the contrary direction as in the rifling head previously described and shown in Figs. 14 and 15.

The copying principle is also used in drilling the various holes for the sights and other parts upon the outside of the guns. In a gun which is intended to hit a target at 2000 or 3000 yards distance, the value of the thickness of a line in half the length of the gun is important; and as all the Armstrong guns are made so that the several parts interchange, absolute precision in the positions of the several holes is essential. Most of the holes have to be drilled on the side of the gun, where the difficulty of entering correctly is greatly increased on account of the surface being oblique to the direction of the holes; so that the drill requires to be guided very steadily, and the ordinary plan of dividing off the holes and the use of a centre punch are altogether inadmissible. A cast iron saddle is therefore made to fit upon the gun and also upon the trunnions, being cast in halves, so that the whole of that part of the gun in which the holes have to be made is enveloped in it. The saddle is correctly made with copy holes lined with steel, the several holes being of the required

dimensions of the holes to be made in the gun. Cylindrical drills are employed, which fitting the holes in the copy give the utmost accuracy to the sight holes without any effort.

Mr. Anderson exhibited a model of the vernier measuring instrument, enlarged 24 times, for the purpose of showing the mode of using the vernier. He explained that in the scale of the instrument itself each inch was subdivided into twentieths, as the subdivisions carried to that extent were found to be of a size convenient in practice for reading quickly by the naked eye. The sliding vernier scale was constructed by marking on it the length of 49 of these twentieths of an inch, and this length was then subdivided into 50 equal parts, so that each subdivision on the vernier was shorter than a subdivision on the main scale by exactly 1-50th of 1-20th of an inch, that is 1-1000th of an inch, whereby the vernier gave the means of measuring to 1-1000th of an inch, although the divisions to be examined by the eye were as coarse as 1-20th of an inch. The vernier was read by observing which of the subdivision lines on the vernier coincided most accurately with one of the subdivisions on the main scale; and the vernier reading was then added to the reading of the main scale previously read off by eye. Thus supposing the fractional reading on the main scale were 3-10ths of an inch and odd, the 3-10ths of an inch or ·3 inch would easily be read off at once by the naked eye, by seeing that the zero of the vernier scale fell somewhere between the ·3 subdivision and the next further subdivision on the main scale. The additional decimal figures to give the exact dimension would then be read also by eye from the vernier in the manner described; and supposing the 42nd subdivision on the vernier were found to be the first that agreed accurately with a subdivision of the main scale, the additional reading would be 42-1000ths of an inch or ·042 inch, to be added to the previous reading of 3-10ths of an inch or ·3 inch on the main scale, thus making the correct fractional reading ·342 inch, which would be the actual dimension correct to 1-1000th of an inch.

The measuring instrument used for making the various gauges employed in the workshops had a magnifying glass mounted on the sliding vernier frame; and the vernier itself, together with the magnifying glass and the back centre or measuring point, was further carried on a second supplementary slide, moved by a fine micrometer screw. In setting the instrument to any required dimension for trying a gauge, the main slide was first set roughly by eye to the proper graduation on the main scale, and clamped in that position by a set screw; and the supplementary vernier slide was then accurately adjusted to the exact dimension by means of the micrometer screw, the vernier scale being read by the magnifying glass.

Mr. E. A. Cowper enquired whether there was any arrangement to allow for the wear of the long brass strips which formed the bearing surface of the broaching block used for the final boring of the guns.

Mr. Anderson replied that there was no means of providing for the wear, and the brass bearing strips all became worn, and required fresh adjustment every time the broaching block was used. With straight bearing strips it was found impossible to get a round hole, the bore being always more or less polygonal, whatever amount of care was used or however slowly the boring was done; but by twisting the bearing surfaces into a spiral form round the broaching block the difficulty was much diminished.

Mr. E. A. Cowper observed that he made a boring machine some years ago for the manufacture of the Lancaster guns, and the plan of boring designed by Mr. Lancaster entailed some difficulty in making the boring bar fit well. The gun was first bored cylindrical; then it had to be bored oval, with the oval twisted. A hollow boring bar was used, revolving concentrically in the gun, and carrying eccentrically within it a solid bar, which carried the cutter and revolved in the opposite direction to the hollow bar, forming an epicycloid movement. The tool projected, then retired, then projected again, and then retired, the double epicycloid forming an oval in one complete revolution. In this arrangement the boring bar had consequently a considerable amount of rubbing in the gun: and the only plan of getting a guide was to make the end of the boring bar fit the cylindrical bore of the gun, and then to thrust it down to the breech of

the gun at the commencement, and bore outwards towards the muzzle, so as to preserve the cylindrical bore as the guide to the last. The whole operation of making the oval bore had thus to be performed with one guiding surface; and it was therefore a point of great importance to get this guiding surface to fit well without any variation from wear throughout the entire length of the bore. He had accordingly turned a broad groove with parallel sides round the head of the boring bar, immediately in front of the cutter, and the bottom of the groove was made slightly inclined or conical. A corresponding brass ring cut into three segments was fitted into the groove, not quite filling the width of the groove; the outer surface of the ring formed the guiding surface, while the inner surface was bored slightly conical to the same inclination as the bottom of the groove. To each segment of the ring was attached a longitudinal wrought iron rod lying in a groove on the outside of the boring bar; then by drawing the three rods forwards by screws, the segments of the ring were drawn up the incline forming the bottom of the groove and were by that means expanded outwards in the gun, thus slightly increasing the diameter of the guiding surface and making up for any amount of wear of its rubbing surface. In this case there was a great deal more wear of the guiding ring than in boring ordinary guns, because the boring bar had a continuous rotary motion for a length of time, the whole of the boring having to be done throughout from end to end of the gun at one operation and by one cutter.

The Chairman enquired what method was employed for making the lathe spindles perfectly true and round, as had been referred to in the paper.

Mr. Anderson replied that the required truth and roundness were obtained only by the usual method of grinding the lathe spindles with an independent grinder running at a high velocity, the lathe spindle revolving slowly in the opposite direction on fine centres. It was a very tedious business to get the spindles true; but when they were once made true, all the work done in the lathe was true also.

Mr. J. Fletcher had had an opportunity of seeing over the Woolwich Gun Factory, and had been much struck with the great accuracy arrived at in the work performed there. Perfect truth was

almost impossible to be attained, and he had himself experienced the difficulties described in the paper from the wear of tools during the execution of a piece of work, particularly when the work was of considerable length, as in cutting a groove or a screw thread for a length of 30 feet; there was then a perceptible difference in the depth of the cut at the two ends, nor was perfect uniformity obtained by setting up the tool through the amount of wear and starting again from the opposite end to work backwards. The accuracy of the work was moreover affected to an appreciable extent by differences of temperature producing expansion and contraction: and he had noticed this effect in cutting a long screw, which altered in length in consequence of being heated by the cutting tool; and unless it were allowed to cool before finishing, it would when cold be perceptibly different in pitch from the regulator. He had also observed the same effect in a set of three surface plates 8 feet long, which would probably coincide perfectly in the morning, but in the middle of the day the thickness of a thin piece of paper might be got between them, and at other times in the day they would vary still more. It was not possible to ensure having them always in the same position, and at exactly the same temperature, or of exactly the same quality of metal; and hence the difficulty of carrying accuracy in engineering work beyond certain practical limits. He enquired whether in boring the guns to so great a nicety as had been described the outside of the complete gun was turned before the boring was done: because if any piece of metal were bored out first, and then had the outside skin turned off, a perceptible change would be produced in the dimensions of the bore previously made, and it would be impossible to attain accuracy in that way.

Mr. Anderson replied that the gun was turned outside with a near approach to the final accuracy, before the boring was done.

Mr. G. H. Bovill asked what effect the firing of the gun had upon the accuracy of the bore, and whether the bore was accurately gauged before and after the firing, in order to ascertain what variation took place in the dimension after several charges had been fired, in consequence of the friction of the shot and the expansion of the metal from the heat and strain.

The CHAIRMAN said there must be a certain amount of stretch in the gun under the severe strain; but it was very minute, and he believed not sufficient to affect the practice with the gun. The finishing process of the boring was deferred till after the proving, and the bore was then made as true as possible in roundness and straightness.

Mr. E. A. COWPER observed that the same plan was carried out with good fowling-pieces, which were always proved before they were finished in the bore.

Mr. W. RICHARDSON had been surprised to see the perfection and accuracy of workmanship attained in the Woolwich Gun Factory, and believed he had never seen the same degree of accuracy in any other works. It would be a great advantage if the engineering workshops throughout the country would endeavour to approach to the same amount of perfection, by employing a better class of machinery and tools, which would produce an important advance in mechanical engineering.

The CHAIRMAN moved a vote of thanks to Mr. Anderson for his paper, which was passed; and observed that the members would have an opportunity of visiting the works at Woolwich and seeing the whole of the processes described in the paper in the manufacture and rifling of the guns; and also of visiting the Small Arms Factory at Enfield, where the same principles had been carried out by Mr. Anderson, and the same accuracy of workmanship attained.

The Meeting was then adjourned to the following day. In the afternoon the Members visited the new Main Drainage Works and Sewage Pumping Engines in process of execution at Greenwich. Some of the principal engineering establishments in London were also opened to the inspection of the Members.

The ADJOURNED MEETING of the Members was held in the Lecture Theatre of the Royal Institution, Albemarle Street, London, on Wednesday, 2nd July, 1862; THOMAS HAWKSLEY, Esq., in the Chair.

The following paper was read:—

ON THE RELATIONS OF POWER AND EFFECT IN CORNISH PUMPING ENGINES OVER LONG PERIODS OF WORKING.

By Mr. CHARLES GREAVES, of Bow.

In investigating the working of steam engines with a view to determine with exactness the quantities of fuel and water consumed in producing a measurable amount of mechanical effect, the author has been led to maintain registers of work comparable with the expenditure of materials used, which he thinks may be of service to engineers; partly because they have been carried on through long periods of working and therefore become data of commercial experience, and partly because the facilities for securing accuracy lay in his own hands, as well as means for carrying out some of the measurements on principles not generally adopted.

The engines which are principally the subject of this investigation are of the description commonly known as "Cornish": that is to say single-acting high-pressure expansive condensing engines, working single-acting pumps through the medium of a beam, as shown in Figs. 1 and 2, Plates 40 and 41, which are longitudinal and transverse sections of one of the Cornish pumping engines at the East London Water Works, the steam cylinder A being 100 inches diameter in this engine. The pumps B are all plunger pumps, and the plungers are loaded with iron weights sufficient to counterpoise the pressure of a hydrostatic column which is the measure of the pressure created in the central station to put in action the supply of water to the eastern part of London. The loaded plunger is lifted by the action of the steam in the cylinder A, and is allowed to descend by gravity at a speed depending on the quantity of engine power in action and the rate at which the water is being drawn away. The chamber of the pump becomes filled when the plunger is raised, and the act of inhaling the full charge through the suction valve C is a portion of the work

which the steam has to perform, and a portion also much subject to variation.

The working of the Cornish engines at the East London Water Works is as follows. The steam is raised in cylindrical single-flued boilers with internal fires to a pressure of 30 to 35 lbs. per square inch above the atmosphere: the boilers are of ample dimensions, and not less than three are at work for each engine; they have large steam chests attached and are all covered up with great care. The engines are worked at all speeds which may be practically included between 4 strokes and 10 strokes per minute. The cylinders are all cased in steam jackets and these again are enclosed in an outer case filled to a thickness of not less than 12 inches with very fine ashes. The cylinder covers have no steam jackets but are well covered in various ways, as are also the steam pipes and upper nozzles or valve boxes. The steam valves are in all cases double-beat gun-metal valves, and in as good order as close care and attention can maintain them. The boilers being filled with steam at 30 to 35 lbs. pressure per square inch, the same pressure fills the steam chest and steam pipes up to the steam valve. The supply for the steam case of the cylinder is taken from the same boilers, and no difficulty exists in maintaining the full heat of the boiler in the steam case, amounting to 282° Fahr. with steam at 35 lbs. per square inch above the atmosphere. The condensed water from the steam case returns by gravitation to one of the working boilers, the cylinders being purposely set at such a level relatively to the boilers as to allow of this continued circulation by mere gravitation, which is not interfered with by the working of the engine, continuing to act during the intervals of work or as long as steam remains in the boiler.

The speed of the engine is regulated by an adjustable cataract: the exhaust valve first and then the steam valve are thrown open by treadle weights, as soon as the catches are detached by the cataract. The valves are closed by tappets on a plug rod D, Fig. 1, Plate 40, first the steam valve E and then the exhaust valve F, the former at a period of the stroke varying in practice between one third and one fifth from the commencement, and the latter at the end of the stroke.

In engines worked on this principle, as also in all reciprocating engines pumping without cranks, there is nothing to limit the strokes of the engine to any exact length. It is necessary therefore that bumpers or catch pieces be provided to restrain the engine at both ends from an undue length of stroke; and thick plates of india-rubber under hard wood blocks are now used for this purpose in place of the spring beams formerly employed. An engine thus arranged, working alone, lifting water from one fixed level to another, would work continuously with one length of stroke and one speed, at whatever it might be set: but in waterworks with direct delivery, that is not pumping into a stand-pipe of constant height of column, but where the levels of the reservoirs vary continually and the velocity of the delivery into the main pipes is subject to continual fluctuation, it is found that a variation to the extent of some inches in the length of stroke results throughout the day; and the engines lengthen and shorten their strokes in obedience to the variable resisting pressure of the column of water. The variable resistance to the loaded plunger in the outdoor stroke causes the piston to stop at a variable distance from the top of the cylinder, a reduction in the resistance causing a greater velocity and a corresponding greater length of outdoor stroke, before the motion is completely arrested by the effect of closing the equilibrium valve. An empirical dimension for length of stroke has consequently to be determined by observation as an average. Each stroke of these engines is an operation complete in itself, including within itself all the changes from rest to rest; and there is no momentum carried on and no arrear of force subsequently supplied.

The stroke of the engine raising the load, technically called the "indoor" stroke, is performed in these engines at the mean velocity of from 500 to 600 feet per minute. When the steam is cut off at 1-4th of the stroke, a 10 feet stroke is frequently performed in 1 second, and 11 feet stroke constantly in 1¼ second; and when cut off at 1-3rd, the 10 feet stroke requires about 1⅓ second. This speed in pumping is almost peculiar to waterworks engines; for in mining engines the same length of stroke generally requires more than 2 or 2½ seconds. Much depends on this velocity. The chamber of the pump having to be filled during the indoor stroke, the dimensions of

the suction valves C, Fig. 2, Plate 41, must be such that the least loss of power may be suffered in drawing the water in; and the adoption of double suction valves has proved very beneficial in economising power. Moreover as it is absolutely necessary for the good working of the engine that the suction valves should be shut quite as soon as the engine concludes the indoor stroke, the lift and loading of the valves are matters requiring considerable attention.

For the purpose of obtaining a high duty, the author's experience would lead him not to put a greater total load on the piston than about 16 lbs. per square inch, including the friction of the engine; this total load being the total pressure on the piston measured by an indicator and averaged over the whole length of the stroke. Now in engines worked in the manner above described at an average speed of about 7 strokes per minute there is no difficulty in maintaining a vacuum in the condenser within $1\frac{3}{4}$ inches of mercury of the atmosphere at the time. Observations on this point have been made for years, from which is deduced an average of 1·66 inch below the atmospheric barometer at the time. Hence the average vacuum maintained in the condenser may safely be taken at 28 inches of mercury, or 13·75 lbs. per square inch. This in action throughout the stroke leaves only the remainder 2·25 lbs. per square inch to be made up by the pressure of the steam, in order to balance the total load of 16 lbs. per square inch on the piston; and therefore a somewhat greater pressure of steam than 2·25 lbs. per square inch above the atmosphere, kept on the piston throughout the whole stroke, would produce motion. If however steam of a much higher pressure be admitted, the motive force will be greater than the load, and it will be necessary to stop the admission of the steam at some point before the end of the stroke, leaving the steam to expand through the remainder of the stroke, in order that the total power may not be in excess of the load to a greater extent than is necessary to produce the required speed of motion.

The accompanying indicator diagrams, Fig. 3, Plate 42, are all taken from one of the engines at the East London Water Works, with five different degrees of cut off, at $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, and $\frac{1}{6}$ of the stroke, but with the same effective load; the effective load being the load to be

lifted, exclusive of the friction of the engine, measured by a pressure gauge in the pump and reduced to the area of the piston. The diameter of the cylinder was 72 inches, and the actual length of stroke 9 feet 7½ inches. The diagrams were drawn successively after working half an hour at each of the different proportions of cut off. They show how as the higher pressure of steam was admitted the earlier cut off was necessary; and how nearly the total power exhibited in the stroke under the different conditions remains uniform, the mean pressure being equal in each case to 15 lbs. per square inch on the piston throughout the stroke, which is therefore the total load on the engine as measured by the indicator on the cylinder, including the friction of the engine. It must however be borne in mind that with the steam cut off at 1-6th and the proportionately higher initial pressure of steam the stroke was made much quicker than with the steam cut off at half stroke, being performed probably at a greater average velocity than 600 feet per minute. The admission indeed of steam at such a high pressure by a double-beat valve approximates very much to a blow on the piston, and must be met by great strength of the moving parts. Figs. 4 to 8, Plates 43 and 44, show the same indicator diagrams drawn out separately; and Figs. 10 to 12, Plate 45, are indicator diagrams from three other engines at the East London Water Works. Fig. 10 is the indicator diagram from the 80 inch cylinder, giving a total load on the piston equal to 14·38 lbs. per square inch, the actual length of stroke being 9 feet 9 inches, and the steam cut off at 1-3rd stroke. Fig. 11 is from the 90 inch cylinder, the total load on the piston being equal to 15·58 lbs. per square inch; the actual length of stroke was 10 feet 7 inches, and the steam was cut off at 1-4th stroke. Fig. 12 is the indicator diagram from the 100 inch cylinder, giving a total load on the piston equal to 16·58 lbs. per square inch, the actual length of stroke being 11 feet, and the steam cut off at 1-4th stroke.

In order to determine with precision the exact point at which the steam valve is closed, an arm was fixed on the valve spindle, having its outer end connected to the rod of an ordinary indicator: then the barrel of the indicator being put in motion in the usual manner, a figure is drawn as the result of the two motions which portrays the

exact rise and fall of the valve on the base line of the stroke. Fig. 9, Plate 44, is a diagram of the lift of the steam valve traced in this way by the valve itself, showing the actual point of cut off in the 72 inch cylinder, corresponding with the five preceding indicator diagrams from the same cylinder. The steam valve is 16 inches diameter, double-beat, and the vertical scale of the diagram is full size, giving the actual lift of the valve. This diagram shows that with the steam cut off at half stroke the lift of the valve is 1·88 inch; at 1-3rd stroke, 1·80 inch; at 1-4th stroke, 1·74 inch; at 1-5th stroke, 1·69 inch; and when the steam is cut off at 1-6th stroke, the lift of the valve is 1·53 inch. The author strongly recommends the use of this contemporary valve diagram to prove the real point of cut off, both as definite evidence particularly applicable to the movement of the valves, and as being easy and convenient of management.

In ordinary registers of steam engine performance it is thought sufficient to give a comparison of the amount of work done, in weight of water lifted to the known height, with the weight of fuel necessary to carry the engine through that amount of work. The registers of duty so long and so ably maintained in Cornwall are based on this comparison; and the ordinary expression of pounds of fuel burnt per horse power per hour, as universally employed elsewhere, is only a different form of the same expression. There is however a defect in the limited information thus given, since it includes in one statement the whole efficiency of the pump, the engine, and the boiler. These registers are indeed invaluable; but if an additional register of the quantity of water ordinarily used as steam can be added, it becomes possible to discriminate between the efficiency of the boiler and the engine, and to investigate the economy of the engine itself without the complication and variations arising from different constructions of boilers, size of fire, quality of coal, and ability of the stoker. The same measurement of the water boiled off is no less a most sure comparative test of the good qualities of the boilers and the fuel; but the investigation of that subject does not come within the purpose of the present paper. The object of the author is to show the quantity of water used as steam in performing the work, with the proportion

which the work actually done bears to the theoretical power of the steam, as deduced in both cases from the final degree of rarefaction of the steam at the conclusion of the stroke.

The true measurement of efficiency in a steam engine is the quantity of feed water used, as has been well shown by De Pambour: and the author having endeavoured to carry out the same plan of measurement can testify most thoroughly to the very exact knowledge of the condition of an engine that is obtained by making the water evaporated per stroke one of the elements of continual registry in the log book or journal of work. The following Table I gives the total

TABLE I.

Consumption of Feed Water per stroke.

	Half year ending	Total No. of Strokes.	Feed Water evaporated. Total.	Per Stroke.	Average.
			Gallons.	Gallons.	
72 inch cylinder	June 1858	686172	445542	0·649	Average 0·615 gal. or 6·15 lbs. per stroke.
	Dec. „	923490	598075	0·647	
	June 1859	662136	390287	0·589	
	Dec. „	1144711	676990	0·591	
	June 1860	1024225	609630	0·595	
	Dec. „	1025356	639250	0·623	
80 inch cylinder	June 1860	901510	679900	0·754	Average 0·761 gal. or 7·61 lbs. per stroke.
	Dec. „	829444	642350	0·774	
	June 1861	510443	393430	0·777	
	Dec. „	740073	554170	0·748	
90 inch cylinder	Dec. 1857	1506952	1484123	0·984	Average 0·997 gal. or 9·97 lbs. per stroke.
	June 1858	1515208	1459477	0·963	
	Dec. „	881126	903950	1·025	
	June 1859	1359688	1328660	0·977	
	Dec. „	1107643	1092930	0·986	
	June 1860	753049	750650	0·996	
	Dec. „	849576	895150	1·053	
	June 1861	659574	690400	1·046	
100 inch cylinder	Dec. 1858	1541134	2246216	1·457	Average 1·453 gal. or 14·53 lbs. per stroke.
	June 1859	963525	1440918	1·495	
	Dec. „	1070430	1558426	1·456	
	June 1860	1334070	1880850	1·409	
	Dec. „	1346310	1903550	1·414	
	June 1861	1476320	2151945	1·457	
	Dec. „	1564425	2323700	1·485	

quantity of feed water evaporated and the total number of strokes made in successive half years, with the resulting average consumption of feed water per stroke; and these figures being the results of actual experience are not specially experimental or exceptional. The continuous measurement of the feed water has been secured by passing the feed for each range of boilers through one of Kennedy's piston water meters. These meters have been specially tested for the purpose and are periodically examined, cleaned, tested, and re-erected or exchanged according to need. When used with due care the author considers them to be perfectly trustworthy at a cost not deserving to be mentioned in comparison with the value of the reliable evidence they afford.

In order that the total load as measured by the indicator may be compared with the quantity of feed water measured in actual consumption in the boiler, it is necessary to ascertain the actual final degree of expansion of the steam at the end of the indoor stroke, and also the theoretical degree of expansion at which the engine, with a perfect vacuum, and apart from loss and friction, would have completed the stroke. The actual final degree of expansion of the steam at the end of the indoor stroke, from its original state of water, is obtained by dividing the capacity of the cylinder with the working length of stroke by the quantity of feed water evaporated per stroke. The following Table II gives the dimensions of the several cylinders and the final degree of expansion obtained in this way, the consumption of feed water being taken from the preceding table.

TABLE II.

Actual Final Expansion of Steam from water.

Diameter of Cylinder.	Area of Piston.	Length of Stroke.	Capacity of Stroke.	Feed Water evaporated per stroke.		Actual Final Expansion.
Inches.	Sq. Ft.	Feet.	Cub. Ft.	Gal.	Cub. Ft.	
72	28·27	9·62	271·95	0·615	0·0987	2755
80	34·91	9·75	340·37	0·761	0·1222	2781
90	44·18	10·58	467·42	0·997	0·1600	2921
100	54·54	11·00	599·94	1·453	0·2332	2573

The highest degree of actual expansion from water that the author has ever observed has been 3000 times with a total load on the piston not exceeding 15½ lbs. per square inch, and 3134 times with a total load of 15 lbs., the steam being cut off at 1-4th stroke in both cases.

The theoretical degree of expansion at which the steam would have arrived at the end of the indoor stroke, in a perfect engine without loss or friction and with a perfect vacuum, is found by obtaining from the indicator diagram the mean pressure throughout the stroke, which is the total load on the piston; and the simple expansion from water or the relative volume of the steam at this mean pressure, that is the number of cubic feet of steam at that pressure produced from one cubic foot of water, is taken from a table of steam pressures. Then the product of this relative volume multiplied by $(1 + \text{hyp log } n)$, the ordinary formula for calculating the result of expansion, will give the theoretical final volume of the steam at the end of the stroke, n being the number of times the steam is expanded in the cylinder. In this way the theoretical final expansion of the steam is found for any total load and any degree of cut off.

In the 72 inch cylinder the total load on the piston is equal to 15 lbs. per square inch, as obtained from the indicator diagram, Fig. 6, Plate 43; and steam of a total pressure of 15 lbs. per square inch is enlarged in volume from water 1670 times. The steam is cut off at 1-4th stroke, and is consequently expanded 4 times in the cylinder; and $1 + \text{hyp log } 4 = 2 \cdot 386$. Hence the product $1670 \times 2 \cdot 386$ gives 3985 as the theoretical final expansion of the steam at the end of the indoor stroke. The actual final expansion is seen from Table II to be 2755, showing the imperfection of the working result to be 31 per cent.

In the 80 inch cylinder the total load on the piston is equal to 14·38 lbs. per square inch, as obtained from the indicator diagram, Fig. 10, Plate 45; and steam of that total pressure is enlarged in volume 1733 times from water. The steam being cut off at 1-3rd stroke, $1 + \text{hyp log } 3 = 2 \cdot 099$. Hence the theoretical final expansion of the steam would be $1733 \times 2 \cdot 099 = 3638$; while the actual final expansion in Table II is 2781, or 24 per cent. less.

In the 90 inch cylinder the total load on the piston is equal to 15·58 lbs. per square inch, as obtained from the indicator diagram, Fig. 11, Plate 45; and the corresponding volume of the steam is 1612. The steam is cut off at 1-4th stroke, and therefore 1 + hyp log 4 = 2·386, which multiplied by 1612 gives 3846 as the theoretical final expansion of the steam. The actual final expansion in Table II is 2921, or 25 per cent. less.

In the 100 inch cylinder the total load on the piston being equal to 16·58 lbs. per square inch, as obtained from the indicator diagram, Fig. 12, Plate 45, the corresponding volume of the steam is 1529; and the steam being cut off at 1-4th stroke as before, 1529 × 2·386 gives 3648 for the theoretical final expansion of the steam. Table II shows that the actual final expansion is 2573, or 29 per cent. less.

These results are given in a tabular form in Table III:—

TABLE III.

Difference of Theoretical and Actual Final Expansion of Steam.

Diameter of Cylinder.	Point of Cut off.	Total Load on piston.	Final Expansion of Steam. Theoretical.	Final Expansion of Steam. Actual.	Difference per cent.
Inches.		Lbs. per sq. inch.			
72	1-4th	15·00	3985	2755	31
80	1-3rd	14·38	3638	2781	24
90	1-4th	15·58	3846	2921	25
100	1-4th	16·58	3648	2573	29

Hence in the 100 inch cylinder, the theoretical final expansion of the steam being 3648 times from water, and the capacity of the cylinder for the stroke of 11 feet being 599·94 cubic feet, as given in Table II, and the weight of one cubic foot of water being 62·3 lbs., the theoretical quantity of feed water necessary to expand into this capacity would be 599·94 × 62·3 ÷ 3648 or 10·24 lbs.: and the author therefore concludes that, with the steam cut off at 1-4th stroke and under a total load of 16·58 lbs. per square inch on the piston, the stroke of 11 feet could not be made with less than 10·24 lbs. of feed water under any theoretical conditions whatever; that is even with a perfect vacuum, and with no loss or friction.

The actual consumption of 14·53 lbs. of feed water per stroke in the 100 inch cylinder, as given in Table I, is equivalent to 20·09 lbs. per *indicated* horse power per hour, that is under the total load of 16·58 lbs. per square inch on the piston; and the average load as measured by a pressure gauge *on the main* leading from the pump being 12·81 lbs. per square inch reduced to the area of the piston, the actual consumption of feed water per horse power per hour measured *in the main* is 20·09 lbs. multiplied by the ratio of 16·58 lbs. to 12·81 lbs., amounting therefore to 26 lbs. of feed water per horse power per hour. If this were evaporated at a rate of 8 lbs. of water per lb. of fuel, the consumption of fuel would be 3·25 lbs. per horse power per hour. Therefore the minimum consumption of fuel in a theoretically perfect engine with the steam cut off at 1-4th stroke would be 3·25 lbs. reduced in the ratio of 14·53 to 10·24, amounting therefore to 2·29 lbs. of fuel per horse power per hour measured in the main.

The standard quantity of feed water required to produce a stroke of known effect having been obtained from the average of so long a period of working, it must be remembered that there are probably several causes by which the consumption of feed water per stroke, as stated in the preceding Table I, may have been accidentally increased. The inaccuracy that might arise from blowing out the boilers while in work has been entirely avoided; but there is a constant liability to loss from possible unknown leaks from safety valves and gauge cocks. The chance of spare boilers put on short of water or put off with excess may be balanced by a contrary proceeding. Extra steam is used in starting, which must tell up with the engine working only 12 hours out of the 24.

The causes by which to explain the difference between the actual power obtained from the steam and the theoretical full power are, the friction of the engine: the possible leakage of the piston, of the steam valve while the piston is in partial vacuum during the outdoor stroke, and of the equilibrium valve while the steam is on the piston during the indoor stroke: and the imperfection of vacuum in the condenser, since it is not to be supposed that an air pump is all the year round

in a condition to work at all hours within 1·66 inches of mercury of the atmosphere. Then the cooling of the piston rod during the exposure of every stroke, the condensation of steam on the cylinder cover which has no steam jacket, and the condensation, if any, of steam on the sides of the cylinder itself, which would be evaporated again and pass away through the exhaust valve into the condenser, are evident sources of loss, continually operating. These it is the duty of the engineer to use every means of diminishing, in pursuit of that theoretical economy which would result in still further reducing the difference that yet remains between the power expended and the useful effect produced: and an important step towards the attainment of this object will be to ascertain an experimental value of the loss arising from each source.

Mr. GREAVES remarked that his particular object in the paper just read was to show that there was a definite ultimate maximum of result to be developed from a given quantity of water: and he considered it was important that this should be clearly recognised, because the question of the practical efficiency of an engine seemed to be generally treated as though the effective work that could be obtained were an indefinite result by reason of deducting an indefinite loss in friction &c. from an indefinite theoretical maximum of power. But he considered the theoretical maximum of power was a definite quantity, and the effective work that could be obtained from it was indefinite only as far as the losses from friction and other causes were indefinite. The calculations given in the paper of the useful effect of the engines at the East London Water Works were based on a comparison of the theoretical and actual volumes of the steam at the end of the indoor stroke, each volume being estimated from the quantity of feed water consumed per stroke, which was capable of very exact measurement by extending the observations over long periods of working.

There was one point to which no reference had been made in the paper: the clearance space in the top of the steam cylinder and in the steam passages, which had not been taken into account in the calculations. The total clearance space in the 100 inch cylinder, including that in the top of the cylinder and in the steam way as far as the steam valve, was not less than 20 cubic feet or $3\frac{1}{3}$ per cent. addition to the capacity of the stroke, in the 90 inch cylinder 15 cubic feet or $3\frac{1}{4}$ per cent. addition, in the 80 inch cylinder 12 cubic feet or $3\frac{1}{2}$ per cent. addition, and in the 72 inch cylinder 10 cubic feet or $3\frac{2}{3}$ per cent. addition to the capacity of the stroke. If the clearance were included in the total capacity of the cylinders, the degree of actual rarefaction of the steam as deduced from that capacity would appear greater; but the ratios of actual rarefaction given in the paper were in all cases within about $3\frac{1}{2}$ per cent. of the practical result. And as regarded the theoretical rarefaction, deduced from the number of times the steam was expanded in the cylinder, the addition of the clearance space would cause the cut off to take place virtually at a later point of the stroke, and would diminish the theoretical rarefaction. The ultimate result of both effects in the case of the 72 inch cylinder would be to make the actual expansion only 25 per cent. less than the theoretical, instead of 31 per cent. less as given in the paper, being 6 per cent. reduction, or 6 per cent. addition to the efficiency of the engine: and in the other engines the difference between the actual and theoretical expansion would be similarly reduced by about 6 per cent., the ultimate differences being only 18 per cent. in the 80 inch cylinder, 19 per cent. in the 90 inch cylinder, and 24 per cent. in the 100 inch cylinder, instead of 24, 25, and 29 per cent. respectively as given in the paper. The actual amount of steam wasted in consequence of the clearance was only the quantity required to raise the pressure in the clearance space up to the pressure at the point of cut off, this space being already filled at the commencement of the indoor stroke by exhaust steam compressed to the pressure that exactly balanced the weight of the loaded plunger. The clearance space had also the effect of raising the line of pressure in the indicator diagrams, particularly towards the end of the stroke.

The indicator diagrams accompanying the paper were not selected as representing any particularly high amount of duty or very excellent form; but rather as showing by the five diagrams from the 72 inch cylinder the different form of diagram that was drawn with the load remaining the same but the expansion varied, as shown in the combined diagram, Fig. 3, Plate 42.

Mr. W. Pole enquired at what point of the stroke the steam was cut off in the ordinary practical working of the engine from which the diagrams had been taken. Experimentally an engine might be treated in various ways, but it was desirable to know what was considered the most advisable point for cutting off the steam in regular practice. One of the engines referred to at the East London Water Works had been very thoroughly experimented upon and described by Mr. Wicksteed and partially also by himself, and in that case the steam was cut off only at 1-3rd stroke.

Mr. Greaves replied that the five comparative diagrams with different degrees of expansion were taken from the 72 inch cylinder; but the engine upon which a great many experiments had been made by Mr. Wicksteed was the 80 inch cylinder, the first engine brought up from Cornwall and the first Cornish engine used for water works at all. In that engine the steam had never been cut off earlier than 1-3rd stroke, for the engine was bought ready built and had small steam passages, so that it was not easy to get a higher degree of expansion in it: but in the 100 inch cylinder that had since been put up by himself, and in the 90 inch cylinder erected by Mr. Wicksteed in 1847, the steam was cut off uniformly at 1-4th stroke, as shown in the indicator diagrams from those cylinders, Figs. 11 and 12, Plate 45. The 72 inch cylinder put up in 1856 was usually worked also at a cut off of 1-4th stroke, and had been worked occasionally at 1-5th and 1-6th: but he did not think extreme degrees of expansion were desirable, as the higher initial pressure of steam then required produced rather a sudden blow on the piston and caused a great strain on the machinery. He had found that a cut off at 1-4th stroke was a very convenient degree of expansion for regular working in such engines.

Mr. W. Pole concurred in considering it very difficult in practice to work with a high degree of expansion in a single cylinder engine, and believed it was generally found best on that account to limit the expansion to a small amount. Theoretically indeed the greater the expansion the more work was got out of the steam, and therefore to get a high duty a high expansion was required: in Cornwall the expansion had been carried as high as ten times in a single cylinder in engines in good condition, and he remembered one engine that was doing the best duty which had the steam cut off at about 1-10th stroke. There could be no doubt however that generally it was objectionable to cut off the steam very early in an engine that was heavily loaded: for this produced a serious blow on the piston, which did the engine a great deal of harm, by straining and sometimes even fracturing the machinery, which was consequently required to be of very great strength. Hence it was important to know that 1-4th stroke was the practical limit to which the expansion was carried in the actual working of the single cylinder engines described in the paper.

Mr. F. J. Bramwell enquired what was the amount of the working expenses per horse power of the engines at the East London Water Works, at the ordinary price of coals in London.

Mr. Greaves replied that the engines worked at the rate of 12*d.* per horse power per day of 24 hours, including all expenses and every kind of repairs, but not interest on capital.

Mr. F. J. Bramwell asked what would be about the original outlay of capital for such engines, that is the first cost of the engine itself and of the engine house, but exclusive of the boilers and the boiler house; and also what was the horse power of the work done: in order that there might be the means of knowing the proportion that the first cost bore to the horse power developed in these Cornish engines as compared with pumping engines having cranks and flywheels.

Mr. Greaves said the power of a 100 inch cylinder Cornish engine working at a fair speed might be taken at about 250 horse power in the work actually done in the main beyond the pump: and the whole first cost of such an engine, with six boilers, chimney,

air vessel, stand pipe, and engine house complete, would be about £23,000 or £24,000. This was equivalent to nearly £100 per actual horse power of work done beyond the pump; but in these Cornish engines the term horse power was seldom used at all in statements of the work done, the duty being reckoned in millions of lbs. raised 1 foot high by the consumption of 1 cwt. of coal, according to the usual practice in Cornwall. The engine house included in the above cost would be one built on a handsome scale and exceedingly massive, enclosing the entire engine; but in Cornwall the house for such an engine was never carried beyond the "bob" wall upon which the beam is supported, and the outer half of the beam worked out of doors, thereby greatly diminishing the cost of the house: this had been done also in an engine put up recently at the Kent Water Works near London, where the pump plunger worked out of doors.

Mr. E. A. Cowper remarked that reference had been made in the paper to the loss that must arise from the top cylinder cover not having a steam jacket, since it was exposed alternately to the high temperature of the steam as it entered the cylinder at high pressure and to the low temperature of the expanded steam at the end of the stroke, and would thus cause some loss by condensing a portion of the steam at the beginning of each stroke: and he thought it was desirable that the piston also should be kept heated by steam, if this could be done conveniently, because the body of the piston must condense a certain quantity of steam at the beginning of the stroke, which, although it became evaporated again towards the end of the stroke, was deprived of its effect as steam in the earlier part of the stroke, and required a corresponding increase in the quantity of steam admitted to the cylinder for each stroke. He observed also that much of the pressure of the steam was commonly lost by wiredrawing it on admitting it to the cylinder, as the indicator diagram from the 80 inch cylinder showed a pressure in the cylinder of only 13 lbs. while the boiler pressure was 30 lbs. per square inch above the atmosphere.

Mr. D. Adamson remarked that the arrangement of the Cornish engines described in the paper appeared to involve a very large outlay in the first cost of the engine, in proportion to the amount of power

obtained, since the mean pressure of steam throughout the stroke was stated to be only 2 or 3 lbs. per square inch above the atmosphere. He thought the application of large cylinders with low pressures of steam was not an economical or advantageous mode of working; and that to get the greatest economy it was necessary to develop the largest amount of force from the steam side of the piston, instead of obtaining more than three quarters of the entire power from the exhaust side of the piston. Moreover the Cornish engine being single-acting, the whole power required for performing the work had to be put into the engine in one stroke, instead of being equally divided between the two strokes; and with so low a pressure of steam as was generally used, and an early cut off, a very large and expensive construction of engine had to be employed for performing a comparatively small amount of work. With pressures of 140 to 160 lbs. now employed successfully in locomotives, there seemed no reason why the required power should not be obtained in stationary engines by the use of much smaller cylinders, working double-acting, and steam of 100 or 120 lbs. pressure, which with suitable boilers would be easily practicable, while the engines would run steadier and would involve a much less extensive accommodation for housing them. At his own works he had had such an engine of about 42 indicated horse power working regularly for 8½ years with 150 lbs. steam, and with a consumption of 2¾ lbs. of coal per indicated horse power per hour: and the first cost of the engine with boilers complete was not more than 20 per cent. of the outlay that had been mentioned of the Cornish engine.

As regarded the degree of expansion in the cylinder, he thought an early cut off was not desirable; for when there was a great difference between the pressure and consequent temperature of the steam at the beginning and end of the stroke, there was then also a great loss in condensation in bringing the cylinder up to the temperature of the initial steam before the piston was moved at all. He had found by experiment in a beam engine that with 60 lbs. steam the maximum economy was obtained when the cut off took place not earlier than 1-3rd stroke; but as the expansion increased with earlier cut off, the condensation increased also, and there was only the same work done

with a much larger expenditure of steam: and he had no doubt that all engines where the cut off was earlier than 1-3rd stroke lost a considerable amount of power by condensation of the steam in the cylinder. He therefore thought it was not desirable to carry expansion in one cylinder to any degree that would involve a greater change of temperature in the cylinder than about 30° Fahr.; and if a greater expansion were desired than was allowed under this limitation, it would be advisable to employ a second cylinder, and even a third if necessary, and also to superheat the steam slightly between the cylinders, to preclude all possibility of condensation in them. By thus increasing the number of cylinders and limiting the degree of expansion, the temperature of each would be kept much nearer to that of the steam throughout the stroke. At the same time a high speed of piston was required, since the absorption of heat was so rapid that the loss by condensation could not be prevented if the speed were low. The consideration of the pressure of steam, temperature of cylinder, and degree of expansion, was therefore of the greatest importance for keeping down both the working expenses of an engine and its first cost.

The single-acting engine on the Cornish principle had he thought some advantage over a pumping engine with crank and flywheel, in the fact that no power was required in the Cornish engine for keeping gearing in motion at each end of the stroke; a certain amount of percussive action was indeed necessary to overcome the inertia of the engine at the beginning of the stroke, but on the other hand the whole engine was brought to a dead stand at the end of every stroke by the whole effective power being completely absorbed in the work done in pumping. Moreover the single-acting beam engine with loaded plunger was clearly preferable to a single-acting crank engine; but with a double-acting engine with crank and flywheel, and with a higher degree of expansion, he believed more power would be obtained from a given consumption of fuel than could be got in the Cornish engine. For the purpose of driving machinery the Cornish engine was admitted to be altogether inapplicable, from the great variation in the power throughout the stroke: but even as a pumping engine he thought its real economy had been overrated, since the most economical results were said to have been attained with pressures of

only 25 or 30 lbs. above the atmosphere at the outside; and if this were the case, a still greater degree of economy might be expected to be obtained by the adoption of higher pressures of steam.

Mr. C. W. Siemens observed that the subject of condensation of steam in the cylinder was now becoming more generally understood than formerly; and the practical remedy which had been suggested, of superheating the steam before it entered the cylinder, had been attended with very beneficial results, especially in the case of marine engines. The relative advantages of superheating the steam were greatest in working it very expansively; hence expansive working might now be carried further with advantage than formerly.

The Chairman enquired what had been taken in the paper as the theoretical maximum of the effect that could be obtained from the consumption of a given quantity of feed water.

Mr. Greaves replied that the theoretical maximum of effect had reference only to the particular point at which the steam was cut off in the cylinder, and was measured by the theoretical volume which the steam would finally occupy in being expanded with that degree of cut off under the total load of the engine. The volume of steam which would be produced at the pressure of the total load from a given consumption of feed water was known from experiment; and the further effect of expanding this steam in the cylinder was ascertained by means of the hyperbolic logarithm of the number of times it was expanded, which gave the theoretical final volume of the steam at the end of the stroke. This was taken as the measure of the maximum effect to be obtained from that consumption of feed water, under the given total load and with the given degree of expansion: and the actual effect obtained was similarly measured by the actual volume of the steam at the end of the stroke. The practical result of this mode of measurement was that in the engines at the East London Water Works the actual power developed was from 70 to 75 per cent. of the theoretical maximum, with the steam cut off at 1-4th stroke.

Mr. J. Fernie remarked that the paper that had been read was one most useful to all employing pumping engines, and it was a great advantage to have complete statements of what had been done in actual work with the different constructions of engines. In pumping engines

with a crank and flywheel he did not think so high a pressure had yet been attempted as had been suggested, of 100 or 120 lbs. per square inch; the highest pressure yet employed in such engines was he believed not more than about 50 lbs. per square inch. At the Clay Cross Colliery near Chesterfield he understood a large pumping engine on the Cornish principle was now being erected to take the place of the small crank pumping engines previously employed there, and he enquired what was the size and cost of the Cornish engine in this case.

Mr. W. Howe replied that at the Clay Cross Colliery they had pumped a large quantity of water for several years past with six small non-condensing engines with cranks, working eight sets of pumps; but the result had been found not at all satisfactory. The pressure of steam in the boilers was not more than 50 lbs., but the engines were not worked very expansively. The coal used was of a very common quality, and therefore an economical result was not to be expected. It had now been determined however to do away with all the small crank pumping engines, and put up one large Cornish pumping engine instead; but the cost of this engine would be much less than that mentioned as the cost of one of the engines described in the paper. In the engine now being erected the cylinder was 84 inches diameter, with a stroke of 10 feet in both the cylinder and the pumps; and it was intended to raise a column of water 18 inches diameter and 600 feet height; consequently the effective pressure on the piston would be about 12 lbs. per square inch. The entire cost of this engine, with a wrought iron beam constructed with two large wrought iron plates one on each side, would be about £4500, including the house, boilers, chimney, and everything to the outer end of the beam: a very different cost from that previously named. The boilers used were common cylindrical boilers, which had been found best suited to the collieries and better for the purpose than the Cornish boilers, as they did not require such skilled mechanics to keep them in repair and would therefore be worked with greater economy. He had no doubt that from £7000 to £8000 would cover everything, including sinking the shaft and putting in the pumps and the engine. The engine house was a substantial brick building with solid ashlar beam wall up to the level

of the cylinder pillar, which was likewise of ashlar stone; but it was only half a house, extending no further than the beam wall.

Mr. E. Reynolds observed that the cost of the engine alone without the pumps or house was about the same for a Cornish engine as for an ordinary beam engine with crank and flywheel; and might be taken roughly at about £40 per inch diameter of the cylinder in engines with 80 or 100 inch cylinders, say £4000 for the engine described: and this would be equivalent to £40 per horse power for a crank engine of 100 commercial horse power; but such an engine would be capable of working at about 2½ times its nominal power or 250 actual horse power.

Mr. E. A. Cowper enquired what was the cost of the engine alone without the boilers, and the weight of the engine.

Mr. W. Howe replied that the cost of the engine alone was about £3000: the total weight with a cast iron beam was about 140 tons, exclusive of boilers and fittings to boilers; but with the wrought iron beam that had now been adopted for the engine the weight would be somewhat less.

Mr. E. Slaughter asked whether Mr. Greaves had had any opportunity of making a comparison of the duty performed per cwt. of coal in the single-acting Cornish engine and in a double-acting engine with crank and flywheel. He believed a general impression prevailed that the Cornish engine possessed some special virtue as a pumping engine, in comparison with the flywheel engine; and wished to know whether it showed in practice any advantage in duty.

Mr. Greaves replied that with the commonest coal that could be bought he believed the Cornish engines described in the paper were yielding about 70 millions duty per cwt. of coal (70,000,000 lbs. weight lifted 1 foot high); and with a flywheel engine of the same size he thought the duty obtained would not be above 50 millions; but he had not had an opportunity of trying a first class flywheel engine that had been brought up to the same degree of efficiency as the Cornish engine.

The Chairman observed that it was desirable to bear in mind the different circumstances under which single-acting or double-acting engines were applicable. The result of his own experience with the

two classes of engines was that the double-acting engine would as a rule do three times the work that could be done by a single-acting engine, for the same size and weight of engine. The double-acting engine used the steam on both sides of the piston, and worked always at least one half faster and sometimes twice as fast as the single-acting engine. Hence for the same power it was much more economical in first cost than the single-acting engine. But the relative advantages must be looked at with regard to the cost of fuel in working, the interest on capital, and the extra cost of wages which was consequent upon employing a single-acting engine instead of a double-acting engine. In general the employment of a single-acting engine necessitated the payment of 30 per cent. more in wages than was necessary in the case of a double-acting engine, the former requiring a better class of men to attend to it. He was not able to understand the reason for reverting to the Cornish engine in place of the previous crank engines for pumping at Clay Cross; for the single-acting engine involved a much larger cost in the construction of the building, and a much greater weight of material in the engine itself for the same power; and it was completely out of place where fuel was cheap, as was the case in many important instances where engines were used for pumping, costing in one instance within his own knowledge only 9*d*. per ton. In other cases where fuel cost as much as 30*s*. per ton, it became a very important matter to consume the smallest quantity possible, and therefore it was then best to employ the single-acting Cornish engine; because in a double-acting engine with a smaller cylinder the passive resistance or friction of the machine was considerably greater per square inch on the piston. But between these two extremes all varieties of intermediate cases arose, and it frequently became a question of very great nicety to determine which was the proper engine to be employed. Moreover commercial considerations sometimes rendered it advisable to pay more in annual expenses for the purpose of economising the first cost of the engine; and here it was more desirable to employ the double-acting engine. No general determination therefore could be arrived at for the use of either engine, but it was highly important that all the facts connected with each should be elicited and discussed. At the Main Drainage Works at Greenwich

the members had had an opportunity on the previous afternoon of seeing the double-acting engines employed for pumping the sewage, which he believed would be found more advantageous under the particular circumstances of the case than single-acting engines would have been, because the lift was very low and variable: but the case of the East London Water Works referred to in the paper was of an entirely different character, the lift being considerable and rendered uniform by means of a stand pipe, and it was therefore more desirable in that case to use single-acting engines than double-acting.

He proposed a vote of thanks to Mr. Greaves for his paper, which was passed; and expressed a hope that he would continue the observations hitherto carried out upon the working of the engines, and communicate the further results of his observations on a future occasion.

The following paper was then read :—

ON THE MANUFACTURE OF HEMP AND WIRE ROPE.

By Mr. CHARLES P. B. SHELLEY, of London.

Ropes are mainly constructed either of the fibres of the Hemp plant (cannabis sativa) or of Iron Wire. Other vegetable substances and other metal wires are also used; but in the present paper only the two important manufactures of hemp rope and iron wire rope are referred to: and as the treatment of the hemp fibres and manufacture of them into rope is quite different from the formation of iron wire rope, the subject naturally divides itself into two branches.

Hemp Rope.—Of the other substances besides hemp which have been found useful and profitable for rope making, the most important are— "manilla", the fibres of which are obtained from the bark of a wild species of banana grown in the Philippine islands, manufactured into a rope commonly known as "white rope"; jute, grown in Bengal, the fibres of which are used for adulterating hemp; cocoa-nut fibre for inferior ropes; Indian hemp or "sunn", the high price of which however keeps it out of the market; and Spanish grass or "esparto". Of these "manilla" is the most common substitute for hemp. The machinery employed for manufacturing any one of these several fibres into rope is similar with slight modifications to that employed for hemp. The intestines, hide, and hair of animals are sometimes used for rope for special purposes; and the Romans are said to have formed ropes by binding together rushes (junci), whence the name "junk" for cable is believed to be derived. A variety of specimens of hemp and of other fibres, together with ropes of different makes, are exhibited, which have been kindly furnished to the writer by Messrs. Wright of Millwall. The manufacture of hemp ropes is still carried on by hand, the ingenious machinery invented for the purpose by the late Capt. Joseph Huddart, and for some time employed at Deptford dockyard, having been abandoned and the old plan of hand making again reverted to.

The hemp plant from which the fibre is derived consists of a woody cylindrical stem, surrounded by a fibrous peel held together by a glutinous substance, the whole being protected by a fine epidermis or skin. The fibrous part, which is the portion used in the manufacture of ropes, is strong, flexible, and tenacious; but the woody core and the external skin are useless, and it is necessary that they shall be separated from the fibres. This is effected by "retting", that is by soaking the hemp stalks in water and allowing fermentation to take place, thus rotting the woody and glutinous parts and leaving the fibres free. The hemp is pulled up by the roots, and the flowers and leaves stripped off, and it is then immersed in a pond or running stream where it is allowed to remain until fermentation takes place, the time of immersion being dependent upon the degree of humidity and temperature of the atmosphere and also upon the quality and growth of the stalks. There are many objections however to this system of retting; the principal is that the stalks not all being of the same strength of growth, and also occupying different positions in the immersed heap, some are liable to suffer from decomposition and be weakened while others may not be sufficiently steeped, rendering it difficult in the processes which follow to separate the woody matter from the fibres, and thus rendering the hemp harsh and inelastic. Another serious objection is that the vapour arising from the putrefaction of the stalks renders the neighbourhood of the stream or pond where the retting is carried on unhealthy. Moreover this mode of retting unavoidably deteriorates and wastes the fibre; for a single stem of hemp is said to be composed of 70 to 80 per cent. of wood and 20 to 30 per cent. of fibre, whereas the fibre obtained by the present method does not exceed 16 per cent. and falls as low as 12 per cent., the remainder being wasted in the retting. Several other modes of preparing the stalks have been tried, such as steaming them, treating them with lime water or alkaline solution, and also adding materials to the mass of soaking stalks with a view of inducing speedy fermentation; but generally these plans have failed and there is still room for improvement in this respect. After the stalks have been dried they are broken at a hand break or by rollers, and the woody part is separated by "scutching", somewhat in the same

way as in the case of flax. The hemp thus prepared is packed in huge bales, each bale of Italian hemp, jute, or manilla, weighing about 2½ cwts.

In order to form the strongest rope out of a given quantity of material, whether hemp fibres or metallic wire, the fibres should be laid parallel alongside one another and secured at the ends, so that they may take any tensile strain put upon them in the direction of their length; the strength of such a rope will be equal to the strength of each fibre multiplied by the number of fibres in the section. Hemp fibres rarely exceed 4 feet in length, so that the above method of making a rope exceeding 4 feet in length will not apply to that material. In order therefore that the fibres may be securely and continuously connected together, they must be placed parallel to one another with the end of one fibre overlapping the end of its neighbour; and to prevent the fibres slipping from one another, friction is produced amongst them by twisting; but as the strength of the fibres is diminished when they are twisted out of the direction of the tensile strain which they are to sustain, no more twist should be given than is necessary to impart sufficient friction to prevent them from slipping and parting endways. It must be remembered that fibres of hemp, like metallic wires, have not the property of "felting", or uniting into one length by a kind of entanglement or matting together, in the manner common to the fibres of wool and other materials used in spinning. If a bundle of parallel fibres be twisted, those on the outer surface will be stretched and strained considerably more than those near the centre; and the further they are from the centre the more will they be strained. Hence in constructing cordage it is necessary to form or build it up gradually from small bundles. Thus the primary object of the rope maker is to get the longest, finest, and strongest fibres which can be economically obtained; and next to lay them in bundles parallel to one another and in continuous juxtaposition, giving them ultimately such a degree of twist that the friction amongst the fibres of the bundle is equal to their tensile resistance.

When the fibres are laid parallel and in continuous juxtaposition, they are said to form a "sliver"; and the sliver when twisted is said

to be converted into a "thread" or "yarn"; and a number of yarns laid parallel and in juxtaposition, bound round by an external "serving" of yarn to hold them together, form "selvagee" which is the simplest construction of rope. If each of the yarns in the selvagee bore its fair share of strain, this would be the strongest kind of rope; but the objection to its more frequent use is that the outside "serving" of yarn frets away and allows water to enter and rot the yarns inside. In order to overcome the objections to selvagee, ropes are made of "strands", each strand consisting of a number of yarns twisted together, the strands being again twisted into the rope; the class of rope depends upon the number of strands and their arrangement. The yarn is twisted in the process of manufacture by a motion to the left from the right, or contrary to the motion of the hands of a watch, producing what is termed in rope making a left-handed twist, being a spiral corresponding to the thread of a right-handed screw. The twist of each strand is in the opposite direction to that of the yarns composing it; and the twist of the rope itself is again in the opposite direction to that of the strands, or in the same direction as that of the yarns.

Ropes are commonly divided into three classes known as "hawser-laid", "shroud-laid", and "cable-laid" ropes. "Hawser-laid" ropes are composed of three strands twisted together; the number of yarns for each strand in different sizes of hawser-laid ropes is dependent on the diameter or number of thread of the yarn. "Shroud-laid" ropes are composed of four strands. "Cable-laid" ropes are composed of three hawser-laid ropes twisted together. "Cablets" are small cable-laid ropes measuring from 1 to 10 inches in girth; larger sizes are termed cables. Shroud and hawser-laid ropes seldom exceed 10 inches in girth. A core or "heart" is used in shroud-laid ropes; it is made of rope and is placed in the centre of the strands, running from end to end of the rope with the strands laid round it. In old worn out ropes the core is always found to be broken in consequence of the stretching of the strands; for the strands being twisted spirally and the core straight, the strands will give more under a load than the core, which cannot therefore be relied upon for adding strength to the rope; but it assists materially in keeping the strands in position

during the manufacture of the rope by hand. Flat hempen ropes are made of four or six ropes, each composed of three strands, and laid alternately to the right and to the left; these are stretched side by side and sewn through in a zigzag direction.

Before the hemp is spun into yarn it has to be freed from dust and hard knots, and the fibres combed so that they may be separate and parallel to one another. This process is called "Heckling", and is done either by machinery or by manual labour; the machinery for the purpose is similar to that used in the preparation of flax. When done by hand, each man is provided with two combs or "heckles", one coarse and the other fine. The heckle is formed of a number of straight sharp-pointed steel pins fixed with the points upwards in an inclined board; the length of the pins, their thickness, and pitch or distance from centre to centre, vary with the material to be heckled, those used for manilla being much finer and closer together than those used for hemp: the pins for heckling hemp are about 10 inches long and about 2½ inches pitch centre to centre. The dresser after untying and opening one of the heads of hemp takes hold of the fibres at about the middle of their length and throws one end of them loosely over the pins, and pulls the bundle towards him; this is repeated until about half the length has been thoroughly combed by drawing through the heckles. The bundle is then turned end for end and the other half heckled in the same way, after which it is finished on the fine heckles. The hemp is now entirely free from knots and has a glossy silky appearance; it is distinguished as "long hemp" and is said to be "topped"; and the handful of hemp is then doubled in the centre and tied at the ends, in which state it is called "doll" and weighs about 2 lbs. The tow or fibres retained by the heckles are called "shorts", and if the shorts are to be worked into the yarn they are tied up with the bundle of "doll". The dresser applies a little oil occasionally to the points of the prongs for the purpose of reducing the friction; and in dressing manilla, soap is sometimes applied to the fibres for the same purpose, in addition to oiling the heckles. Each bale of Italian hemp, jute, or manilla, weighing 2½ cwts. or 280 lbs., loses by heckling about 80 lbs. of "shorts" and 10 lbs. of waste, leaving 190 lbs. of "long hemp" from the bale. One dresser heckles in a day 8 cwts.

(finished weight) of St. Petersburg hemp, or 2 cwts. of manilla, or 1½ cwt. of jute.

The next process which the fibres undergo is that of Spinning into yarns. Hand spinning is done on a long strip of ground called the rope walk, which is generally covered by a low roof: sometimes the shed has an upper floor with a low roof, and then the spinning is done on the upper floor and the other parts of the manufacture on the ground. The length of the walk and shed is about 1230 feet or a little over 200 fathoms, and the width about 30 feet. The tie beams of the roof are placed every 30 feet or 5 fathoms apart, and carry a row of hooks on the underside. That end of the walk at which the spinning machines are placed is called the "head" or "fore end" of the walk, and the opposite end is the "foot" or "bottom end" of the walk.

The Hand Spinning Machine, shown in Figs. 1 and 2, Plate 46, is formed of two cast iron frames with a band wheel A between them, driven either by a man at the winch handle at the back or by steam power. A band passing round the wheel passes over twelve wood rollers or "whirls" B, 1¼ inch diameter, as shown enlarged in Fig. 3, fixed on steel spindles about ⅜ inch diameter which revolve in notches or bearings in the brass discs C screwed in the frames of the machine: the spindles are kept in their bearings by a riband of wrought iron screwed upon the outside of the frame. On the back end of the spindle is a shoulder, and between this and the brass disc is a loose collar, to take the pull of the yarns in spinning; the spindle is kept in by a finger D fixed on the back of the frame. The front end of the spindle is drawn out into a hook E. The notches in the brasses C, shown enlarged in Fig. 4, are for the purpose of forming fresh bearings for the spindles; there are eight notches in each brass, and when one notch is worn down the brass is turned to bring another notch round: when the whole of the notches are worn down a new brass is put in. The twelve hooks and "whirls" are set upon the semicircular upper part of the machine, and are made to revolve by the band which passes over them from the driving wheel A.

Each spinner before beginning to spin takes up a bundle of hemp sufficient in quantity to spin one "thread" of yarn of the required length; he places the "bight" or middle of the length of the fibres in front of him, and turns the ends round his waist, crossing them behind. If the "shorts" are to be worked into the yarn they are tucked below the bight. Each spinner carries in his right hand a piece of stout list. There are twelve spinners to each machine, one to each hook. The spinner draws from the bight or front of the bundle round his waist a sufficient quantity of fibres for the size of the yarn or thread about to be spun, thus forming a "sliver", which he twists with his fingers and hooks the bight of the sliver on to one of the revolving hooks of the machine. He then walks backwards towards the bottom of the rope walk, drawing the hemp from his waist and forming a sliver with his left hand, pulling some of the fibres back if they come forward too quickly and drawing some forward if there are not enough to keep up the required size of yarn. The sliver passes through his right hand, with which by means of the piece of list he firmly grips it, so as to "form" the yarn. The spinner thus prepares the sliver and forms the yarn, while the machine gives it the twist. Care must be taken not to place the ends of one set of fibres too near to the ends of the next set, not giving them sufficient lap, otherwise the yarn will part by the fibres slipping endways from one another; and also to keep the fibres even and regular in thickness, in order that the yarn may be of equal strength throughout. The spinner's pace in walking backwards must be uniform and in accordance with the speed of the revolving whirls. The speed of the whirls and the amount of twist of the yarn is dependent upon the quality of the rope to be manufactured.

The twelve spinners are divided into three sets of four each; four risers, four middlemen, and four leaders. The four risers work from the four hooks on the left side of the machine, the four middlemen from the four middle hooks, and the four leaders from the four hooks on the right of the machine. All the twelve spinners start at once from the machine in the morning. The four risers spin down the walk a yarn 1-3rd of 160 fathoms long, and then stop, while the middlemen and leaders continue to spin past them. The four yarns of the risers

are now unhooked from the whirls by a man at the top of the walk, and are passed each through a hole F in the frame of the spinning machine, Fig. 1, Plate 46, to a reel at the back, upon which they are wound; the men at the bottom end of the yarns still hold on so as to prevent the yarn from untwisting, and follow it up to the machine as it is wound on to the reel. They then twist the ends of these yarns on to one of the holding pins G on the cross bar of the machine frame, and start spinning again with four fresh yarns which they will this time spin down to the whole length of 160 fathoms before stopping. The four middlemen spin down the walk a yarn 2-3rds of 160 fathoms long, and then stop, while the leaders still go on and pass them. Their four yarns are taken off the hooks of the machine and spliced on to the ends of the four yarns which were left on the holding pin by the risers; the yarns of the four middlemen are then wound on to the reel, the men following them up the walk and fastening the ends on to one of the holding pins: the middlemen then start fresh yarns of 160 fathoms length and spin down the walk. The four leaders spin down the walk a yarn 160 fathoms long, and then they also stop, and their four yarns are taken off the hooks and spliced on to the ends of the four yarns left on the holding pin by the middlemen; the yarns of the leaders are then wound up on the reel, followed up by the men. So they go on till breakfast time, the three sets of men never being up at the machine together, and never more than four being there at one time, so that the three sets are always separated. After breakfast the risers commence with the 2-3rds lengths and the middlemen with the 1-3rd lengths, and thus the quantity of yarn spun is equalised between them.

As the spinner proceeds down the walk he tosses the yarn with his left hand on to one of the hooks in the rafters in order to support it; and in coming back he jerks it off again. The distances of 1-3rd, 2-3rds, and 160 fathoms are chalked on the side of the shed, and as the spinners of each set come to the distance they shake their yarns and thus signal to the man at the machine for the yarns to be unhooked and reeled up. Each spinner is paid in London 9*d*. for spinning six threads or yarns, each 160 fathoms long; this is called "one quarter's work", and each spinner spins four threads in an hour.

The yarns are distinguished and designated by their size or number of thread, every size being numbered; the ordinary numbers, beginning with the coarsest yarn and going to the finest, are 18, 20, 25, 30, and 40. No. 20 is the most usual size and is employed for "London staple cordage"; No. 25 is used for government yarns, No. 30 for bolt rope yarns or the finest description of cordage, and No. 40 for whale lines. In spinning No. 20 size the "shorts" are always worked in with the "long hemp"; but for finer sizes, 25, 30, and 40, "long hemp" alone is used, in order that the yarn may be even and smooth. The size of the yarn is determined by the number required in each strand to make a rope of 3 inches girth with three strands; thus the size of No. 20 yarn is such that 20 yarns in each strand will make a rope of 3 inches girth with three strands. No. 20 is said to be the usual "grist"; Nos. 25, 30, and 40, are said to be finer "grists".

If the cordage is to be tarred, it is done at this stage of the manufacture, before the yarns are formed into strands; but the process of tarring the yarns will be described subsequently.

When the reel behind the spinning machine has been filled with the four lengths of yarns spun, it is taken to the Winding Machine, shown in Figs. 5 and 6, Plate 47, which separates the four yarns on to four separate bobbins A A, and also reverses the lay of the yarn end for end so that the fibres may lie in the proper direction for passing through the next process. Fig. 5 is a front elevation of half the length of the machine, showing two of the four winding bobbins A A; and Fig. 6 is an end elevation. The bobbins are driven from the drum B which extends the whole length of the machine, by means of straps passing round the four riggers C C fixed on the vertical spindles that carry the bobbins A. The full reel containing the four yarns from the spinning machine is mounted on a temporary frame behind the winding machine, and the ends of the four yarns are led to the bobbins over a sliding bar D, which has a vertical reciprocating motion given to it by the cam E and levers F, for the purpose of filling the bobbins regularly and equally from end to end. Other forms of winding machines are used, but the principle of construction is the same in all. When the

four bobbins are filled they are replaced by empty ones, until the whole of the reel from the spinning machine is wound off upon bobbins. The four full bobbins are then taken away and placed vertically in a large wooden frame called the bobbin frame, which holds from 150 to 200 bobbins. Each bobbin contains about 14 lbs. of yarn.

The next process is that of twisting a number of yarns together into a strand, which is termed "Forming" and is done in the "forming" machine and in the shed covering the rope walk. Having ascertained the number or size of the thread that is of sufficient thickness to form the required strand, the number of yarns corresponding to that size of thread are selected; and the ends of the yarns of this size are drawn from the bobbins and brought in a converging direction to a square iron plate, called the "register" plate, perforated with a number of round holes. Each yarn is made to pass through a separate hole in the register plate, and the yarns all converge thence into one common point through the forming board, in which is a taper steel tube with a trumpet-mouthed taper hole through it. The hole in the tube varies in diameter for each size of strand and is selected by a gauge: the diameter of the tube for one of the strands for a rope of 3 inches girth is 8-16ths inch at the small end and 9-16ths inch at the large end, and for the strands of a rope of 2 inches girth it is 5-16ths inch at the small end and 7-16ths inch at the large. The convergent yarns are entered into the tube at the large trumpet-mouthed end, and are forced through, fitting tightly into the tube; they are thus squeezed together previously to being attached to the forming machine.

The Forming Machine for twisting the hemp yarns into strands is shown in Fig. 7, Plate 48. It is mounted on wheels and made to travel along the length of the rope walk by the endless rope A, called the "fly rope", which passes round pulleys at the top and bottom of the walk and acts as a driving rope, being driven by an engine. This fly rope takes a turn round the whelp wheel B, which gives motion by gearing to the drum C and the twisting hooks or "nibs" D for forming the strands. A fixed rope E called the "ground rope", made fast at the ends of the walk, is coiled round the drum C, so that by the revolution of the drum the machine is made to

travel along the walk. During the travel of the machine the yarns hooked upon each nib are drawn out and twisted together into a strand; each nib taking the number of yarns required to form the strand. The speed of revolution of the hooks is regulated according to the kind of rope into which the strands are to be made; and the great object is to adjust the rate of travel of the machine in relation to the speed of the hooks so that the strands may receive the proper amount of twist in a given length. For this purpose the staves of the drum C which gives the travel of the machine are made capable of being shifted to or from the centre of the drum by means of adjusting screws, so as to diminish or increase the rate of travel.

In the next process the strands are "laid" into a rope by two "Laying" Machines, one at the upper end of the walk and the other at the lower end, shown in Figs. 8 and 11, Plates 49 and 50. In this process, instead of being twisted together as the yarns are in the previous "forming" process, the strands are placed or "laid" in their spiral position in the rope without being twisted. The laying machine at the upper end of the walk, Fig. 8, Plate 49, is fixed, and the three strands to form the rope are attached to the hooks D, which are made to revolve in a similar manner to those in the previous forming machine, by the fly rope passing round the wheel B. The lower end laying machine, Fig. 11, Plate 50, is left free to travel part way up the walk as the length of the strands becomes shortened by their being laid into a spiral in the rope. The wheel B here drives the two "forelocks" A A, to one or other of which the strands are made fast, according as the twist of the rope is to be right-handed or left-handed. The three strands for the rope are stretched tight along the length of the walk from the hooks D of the laying machine at the upper end to the forelock A of the lower laying machine, and are supported off the ground and kept separated by means of posts, called "samson posts", placed at every 5 fathoms length, with pegs to carry the strands. A taper piece of wood with three grooves, called the "laying top", shown enlarged in Figs. 9 and 10, Plate 49, is then inserted between the strands close to the lower machine, with its smaller end towards the forelock A, one of the strands lying in each of

the grooves. A transverse hole is made through the laying top, through which is passed the "top stick" or handle that the top is held by. The laying tops are made of various sizes according to the size of rope required: for a rope of 3 inches girth the top is 12 inches long, 10 inches diameter at the larger end, and 8 inches at the smaller. When the rope is more than 3½ inches in girth, a "top cart" is used for supporting the top.

The laying machines being now put in motion, the revolution of the forelock A, Fig. 11, Plate 50, gives the twist or "hard" of the rope, while the laying top is firmly held by the handle from turning. The hooks D, Fig. 8, Plate 49, at the other ends of the strands are made to revolve in the opposite direction to the forelock A which is twisting the rope, so that the twist put into each of the individual strands at the point where they are united into the rope immediately behind the laying top is taken out again by the hooks at the upper end. The laying top is gradually pressed forwards by the closing of the strands upon one another behind it; its motion requires to be very regular, and it is prevented from moving forwards too fast by a "tail" or piece of rope attached to the top handle, which is coiled round the rope already twisted, and thus acts as a drag to the top. The two laying machines must be driven at exactly the proper speed relatively to each other, so that the twist put into the separate strands at the laying top may be exactly neutralised by the revolution of the hooks: otherwise if the hooks revolve too slow, they will partially untwist the individual strands, since the twist of the yarns in each strand is in the contrary direction to that of the strands in the rope; or if too fast, the strands will become twisted tighter. In order that the man holding the laying top may find out how the machines are working, whether too fast or too slow relatively to each other, he makes a mark on one of the strands close to one of the supporting posts: if the strands are being twisted too fast by the hooks of the upper laying machine, the mark on the strand advances towards the upper end of the walk, from the yarns themselves becoming twisted tighter together in each strand, whereby the length of the strand is shortened; but if too slow, the mark recedes towards the lower end, from the partial untwisting and consequent lengthening of the

individual strands. In laying the strands care is required with regard to the angle that the strands take. Should the tension on the strands become unequal, the required additional twist is given to those which have got slack by throwing out of gear those hooks of the upper laying machine to which the tighter strands are attached, and allowing the others to continue revolving until all the strands have again become equally strained. As the formation of the rope proceeds, the lower laying machine is gradually drawn up the walk by the shortening of the strands as they are laid together into the rope; and weights called "press weights" are placed on the frame of the machine to retard its motion and hold the rope tight enough during the laying. Formed strands of 180 fathoms length will make 120 fathoms of hawser-laid rope; the length of the strands will be determined by the length of rope required.

After the rope is taken off the laying machines, it is coiled on to a drum driven by steam power, being guided from end to end of the drum by the workman, whose hands are protected by a piece of old cordage twisted on the rope that is being coiled; this gives a polish and finish to the surface of the rope.

The previous description has referred only to ropes manufactured by hand. In the application of machinery to this manufacture, which is next to be considered, Mr. Cartwright appears to have invented the first rope making machine, which is the basis of others since constructed, his "Cordelier" having been brought out in 1792. Fig. 12, Plate 51, shows a sketch of the cordelier, which revolves on the horizontal shaft A, the laying top B serving as the bearing at one end of the shaft, having holes through it for the strands to pass through. In the discs C C fixed on the shaft A are centred the three horizontal spool frames D, carrying the spools E which contain the three strands to be laid together. As the cordelier revolves, the axes of the spools are preserved constantly parallel to themselves by the spool frames D being made to rotate on their bearings once for every revolution of the machine, by means of the pinions F on the spool frame bearings, and the counter wheels G gearing into the central dead wheel H, which is of the same diameter as the pinions F and is

held stationary while the shaft A revolves within it. The bearings at the other end of the spool frames D are hollow, for the strands to pass through to the laying top B. The strand is drawn off the spool by the pair of delivering rollers I, which receive motion by a worm wheel J on the axis of one of them gearing into the worm K within which the spool frame revolves. The drawing rollers L L draw the finished rope forwards as fast as it is made, and hold it from turning.

This machinery was a few years afterwards improved upon by Capt. Huddart, who constructed machines that were used for a number of years at the Deptford dockyard for spinning the yarns and for the manufacture of ropes and cables; and the author is mainly indebted for the following particulars of the construction of this machinery to a description and drawings given in the Professional Papers of the Royal Engineers by Mr. John Miers.

The Spinning Machine for converting sliver into yarn is shown in Figs. 13 and 14, Plate 52. Fig. 13 is a portion of the front elevation of the machine, showing four of the twelve spinning tubes A A; and Fig. 14 is a transverse section. The sliver, previously formed by another machine, is contained in the twelve cans B, which are driven rather faster than the spinning tubes A in order to give a slight preparatory twist to the sliver. The spinning tube A, shown enlarged in Figs. 15 and 16, has a spring clip C at the top, which grips the thread spun from the sliver and twists it with great rapidity, thus effecting the spinning. The thread so formed is then subjected to a considerable amount of tension by being drawn through the compressing jaws D, Figs. 15 and 17, and round the stretching pulleys E, F, and G, Fig. 14, the last of which is a double pulley with two grooves. The thread passes first over the pulley E, then under one of the grooves in the pulley G, over the pulley F, and again over the second groove of the pulley G, whence it passes away to a winding drum at the back of the machine. The main driving shaft of the machine is driven from the engine by a belt over the fast and loose pulleys H. There are three horizontal winding drums behind the machine, upon which the yarns are wound, each drum taking the yarns from four of the spinning tubes: the yarns are delivered upon the drums through holes in a longitudinal traversing bar, which is moved endways backwards

and forwards by a rack and pinion so as to guide the yarns from end to end of the drums alternately.

If the ropes are to be tarred the tar is applied to the yarns on leaving the spinning machine. For this purpose they are first wound off from the drum behind the spinning machine upon a winder called a "whimwam", made of a light open frame of iron and wood revolving on a horizontal shaft. The loose ends of the four yarns on the drum are attached to a hook at the right end of the winder, which is then turned by a winch handle to wind the yarns on, the yarns being guided on from end to end by a traversing plate with four holes in it which receives the required traverse motion from the shaft of the winder. On reaching the left end of the winder the yarns are doubled round the hook at that end, and the winch is then turned in the opposite direction, winding the yarns on till they reach the right end, where they are similarly doubled round the hook at that end, and the winding is then again reversed. When a sufficient quantity of yarn has been put on the winder, the hook at one end is taken out and the yarn is uncoiled from the winder, thus forming a long skein called a "haul", which is then coiled upon a small circular revolving platform called a "turntable", about 4 feet diameter, mounted on wheels. The haul of yarns is then taken to the tarring shed, and uncoiled from the turntable into a cauldron of tar heated by fire or steam; one end of the haul is lifted from the tar, and by means of a capstan is drawn through a sliding nipper or squeezer for the purpose of squeezing out the superfluous tar from the yarns. After the haul has lain for some time, the longer the better, the four yarns are separated and wound on to four bobbins by the winding machine previously described; and are then passed to the bobbin frame ready for being twisted into strands. Capt. Huddart did not make the yarns into a haul previous to tarring, but passed them from bobbins direct from the spinning machine through the tar and thence through nippers to the register plate of his registering machine about to be described. The length of a haul is 55 fathoms; it contains about 144 threads and takes about 20 minutes to pass through the squeezer from the tar cauldron, that is about 16 feet in a minute. The tar used

should be the best Archangel tar, of a good bright colour, and heated to a temperature of 212° Fahr. The usual proportion of tar remaining in the yarns is from one quarter to one fifth of the weight of the untarred yarns. The yarns when tarred ought to be of a bright brown colour.

The "Registering" Machine, shown in plan in Fig. 18, Plate 53, is for the purpose of twisting the yarns into a strand and winding the strand upon a drum as fast as it is formed. The whole machine revolves with rapidity on the horizontal bearings A B, being connected with the driving power by a sliding friction clutch at B. The strand enters through the hollow bearing A, which grips it tight and thus twists the yarns into the strand by its revolution. The strand is drawn in by the pair of drawing pulleys C, taking half a turn round each, and is delivered upon the winding drum D by the guiding frame E, which is made to move from end to end of the drum by means of a stud on the frame working in a spiral groove cut in the barrel F. The drawing pulleys C, winding drum D, and grooved barrel F are all driven from the spur wheel G gearing into a stationary pinion fixed to the plummer block in which the bearing A revolves. As each successive coil of strand wound on the drum D increases its diameter, whereby an increased tension would be thrown on the strand, a friction clutch is inserted at H in the intermediate shaft which communicates the driving motion from the drawing pulleys C to the winding drum D, in order to prevent the drum from overwinding the pulleys, the friction being adjusted to the exact limit of tension desired in the strand. The guiding frame E which delivers the strand from end to end of the winding drum vibrates on a centre at I, and its rate of travel is varied for different sizes of strand by changing the worm wheel J on the spindle of the grooved barrel F; the universal joint K allows of the driving worm being set at different inclinations for gearing into a larger or smaller worm wheel J.

The strand made by the registering machine is wound off the drum D on to a loose reel, so that when transferred to the drum of the spool frame in the laying machine it may lie the same way end for end as on the drum D, in which state it is ready for being laid into a rope. The length of the strand is measured by passing it over a pulley of definite diameter, to which is attached a counter with a dial

indicating the number of fathoms of strand that have passed over the pulley.

The Rope Laying Machine for laying the hemp strands into rope is shown in Figs. 19 to 22, Plates 54, 55, and 56. Fig. 19, Plate 54, is a general elevation; Fig. 20, Plate 55, a plan at the top, and Fig. 21 a sectional plan through the spool frames; Fig. 22, Plate 56, is a side elevation of one of the spool frames to a larger scale. The three spools A, Fig. 19, Plate 54, filled with strand from the registering machine last described, are carried in the vertical spool frames B, which are centered at top and bottom in the main frame C of the machine. The entire machine revolves round the fixed centre shaft, and is driven by the small bevil pinion D gearing into the wheel E at the bottom of the main frame C. The spool frames B are made to rotate on their axes during the revolution of the machine by means of the pinions F on the spool frames and the counter wheels G gearing into the dead wheel H, which remains stationary, being fixed on the centre shaft of the machine. If the pinions F were of exactly the same diameter as the dead wheel H, the spool frames would make exactly one rotation on their axes for each revolution of the machine, and the spools would be preserved constantly parallel to themselves while the machine revolved, so that the strands would be laid into the rope without any additional twist in the individual strands. But in order to ensure the yarns in each strand being thoroughly closed upon one another, a slight additional twist or "forehard" is given to each strand in the act of laying it into the rope, by making the spool frames perform rather more than one rotation on their axes for each revolution of the machine, since the twist of the yarns in each strand is in the contrary direction to the twist of the strands in the rope. The pinions F on the spool frames are therefore made of smaller diameter than the dead wheel H in the proportion of 13 to 14. From the spools A the strands are drawn off round the stretching pulleys II, as shown dotted in Fig. 22, Plate 56, which are driven by bevil gearing and pinions J from a dead wheel fixed on the centre shaft at the top of the machine, with counter wheels and pinions K similar to those at the bottom. The strand is pressed tight into the

groove of the upper stretching pulley I by the small tightening pulley L, Figs. 22 and 23. The spool A is retarded from unwinding too fast by a friction break which is adjusted to any degree of tightness required. The strands pass up through the hollow bearings at the top of the spool frames B and through the pinions K, and are curved over the oblique guiding rollers M, which are fixed at varying inclinations in order to prevent the strands from slipping off. The three strands then unite at the centre and are laid together into the rope by the revolution of the machine, each strand being laid into the rope with the required amount of "forehard" by the simultaneous rotation of its own spool frame in the contrary direction to the machine. The newly made rope is carried upwards to another machine, where it is stretched over and under three pulleys driven by steam power; and as it passes from the last pulley it is compressed by a roller kept against the rope by a strong steel spring. It is afterwards finally coiled away in a warehouse.

There were three rope laying machines at Devonport dockyard and they were calculated to make about 3000 tons of cordage per year of 313 days. Of this amount the largest machine would make 2000 tons of cables and hawsers of large size, the cables ranging from 14 to 24 inches girth and the hawsers from 7½ to 12½ inches girth; the second machine of intermediate size would make 700 tons of cable-laid ropes from 8 to 16 inches girth and hawsers from 5½ to 7½ inches girth; and the smallest machine would make 300 tons of cablets from 5½ to 7½ inches girth and shroud-laid ropes from 3½ to 5 inches girth. The average cost including all charges of the establishment, engine power, repairs of machinery &c., is said not to have exceeded 17*s.* 4*d.* per ton of cordage made, when the whole machinery was employed to the fullest extent of its capability; the cost by hand at the same period being stated to be 24*s.* per ton.

The Strength of hemp rope varies considerably, and depends principally on the quality of the hemp from which it is made, the number of yarns composing the strands, and the manner in which the ropes are laid. The average strength of each yarn in hawser-laid ropes is found to be greatest with the smaller sizes of ropes. Shroud-laid

rope made with four strands is about one fifth weaker than hawser-laid made with three strands, on account of the additional twist or "hard" which is given to the shroud-laid; and cable-laid rope is about one third weaker than hawser-laid rope. The strength of these three different lays is therefore in the proportion of cable-laid 10, shroud-laid 12, and hawser-laid 15. The relative breaking weights of ropes made from the three most ordinarily used materials are stated to be as follows: taking the breaking weight of St. Petersburg hemp rope at 100, that of Italian hemp rope is 107, and that of manilla rope 73. Tarred rope is weaker than untarred, other circumstances being the same; for the quality of the tar seriously affects the strength of the rope. Hence the strongest ropes are hawser-laid or three-strand ropes made of untarred Italian or Russian hemp.

Wire Rope.—The second branch of the subject of the present paper is the manufacture of Iron Wire Rope, which although at first made by hand is now made exclusively by machinery; and the writer is indebted to Mr. Archibald Smith for kindly furnishing the information on this branch of the subject.

Wire ropes were used as early as 39 years ago for the supporting cables of a suspension bridge at Geneva; and also for the Freiburg suspension bridge of 807 feet clear span, erected 27 years ago. The wire ropes in the latter case, shown in Fig. 24, Plate 57, are constructed of twenty bundles or strands of straight iron wire 0·125 inch diameter, stretched parallel, forming a rope 5½ inches diameter, and bound round with wire at 2 feet intervals.

The first form of wire rope regularly manufactured was made about 27 years ago, and was known as "Selvagee", shown in Figs. 25 and 26, Plate 57. It consisted of a number of hard or unannealed wires, of about 12 to 16 wire-gauge or 0·110 to 0·065 inch diameter, which were stretched parallel and bound together by a fine wire of about 20 wire-gauge or 0·036 inch diameter, wound spirally around; after which a "parcelling" of woollen list was also wound round in the contrary direction, with the edges lapped so as to cover the wires entirely: the rope was completed by a service of tarred yarn wound on in the contrary direction to the list. The

method of making the rope was simply to warp or stretch the wires at a uniform tension over two hooks set at the distance of the length of rope required to be made, passing the wires backwards and forwards over the hooks as many times as was necessary to make up the size required. A solution of india-rubber boiled down in linseed oil with a mixture of resin and tar was rubbed carefully into the body of the rope, previous to binding up; and after the binding wire had been wound on, the solution was again applied to the exterior wires to prevent oxidation, the process of galvanising being unknown or not practised at that time. The "parcelling" of list was also saturated with the solution, the yarn being tarred as usual. The binding and parcelling were always done by hand, before the rope was taken off the hooks; but the service of yarn was usually laid on by a machine for that purpose, though occasionally also by hand. The method of attaching the fittings, such as shackles, thimbles, and dead eyes, was either by forming an eye during the process of warping to receive them, or by inserting the end of the rope stripped to the wires into a conical socket attached to the shackle, and turning back the ends of the wires so as to prevent the rope being drawn out. But more generally the fittings were "turned in", that is the end of the rope was doubled round and "seized" or bound to the standing part. It will be seen that it was very difficult to splice this form of rope, owing to the absence of twist or "lay".

Ropes thus made were exceedingly rigid and non-elastic, but possessed greater strength than any other construction; in fact the entire strength of the wire was preserved. The "parcelling" and "service" added to the size, but not at all to the strength, being intended only for protecting the wires. The want of elasticity and pliability, together with the difficulty of fitting and the constant wear of the "service" of yarn, acted somewhat prejudicially against the introduction of this first form of wire rope on an extensive scale; yet it was used in the royal navy and mercantile marine, and also for suspension and tension bridges: for the latter purpose it is still used, especially in California, where a large number of wire rope suspension bridges are now being erected to replace those destroyed by the late floods.

The machinery for making these "selvagee" ropes consisted simply of the two hooks over which the wire was warped, which were attached to moveable posts set at the required distance asunder. The "serving" machine was a long wood trough extending nearly the entire length of the rope ground, having a revolving shaft at each end with a hook at its extremity, and carrying a fast and loose pulley, over which a driving band passed. The two serving hooks were driven at the same speed of about 400 revolutions per minute: and the shifting forks of the driving bands were connected by a cord extending throughout the length of the ground, so that the workman could stop or start the machine at any part. An ordinary serving mallet was employed for laying on the yarn, and was guided by the workman who also regulated the tension, the yarn being supplied from reels hung overhead.

The next description of wire rope was known as "Formed" rope, shown in Figs. 27 and 28, Plate 57, and was introduced about 25 years ago. It consisted of a number of soft or annealed wires, usually about 14 wire-gauge or 0·085 inch diameter, "formed" or twisted into a strand, but with little or no regard to regularity; and four of these strands were "laid" into a rope, though this number was not always the same. The number of wires was varied according to the size of rope required, and occasionally the size of wire was altered to suit circumstances. These ropes closely resembled ordinary hemp ropes in appearance. The twist caused by "forming" the strands remained in the wire as a permanent set, and the strands were "laid" together with an extra amount of twist or "forehard" in each strand, which was necessary to keep the rope together. Little or no injury was done to the wire by this process, owing to its being annealed, and also from the length of the twist of the wires in each strand, which was usually about 12 inches pitch; but it would be almost impossible to use hard wire in this manner.

The "formed" wire ropes possessed great pliability and some amount of elasticity; they were readily spliced and fitted, like ordinary ropes, and though not so strong as the "selvagee" wire ropes, they possessed many advantages and were more easily introduced. Their

adoption for rigging, incline, and traction ropes, became extensive; and this construction was the first wire rope used on the Blackwall Railway. The small size and soft nature of the wire used offered little resistance to exterior friction, and when employed as incline or running ropes they soon flattened and wore out. The irregularity with which the wires were "formed" or twisted into strands, frequently crossing and recrossing one another, and the great difference in the length of the wires as well as the short "lay" of the ropes, amounting to only 4½ inches pitch, materially assisted to destroy them. Even when used simply as standing rigging, the wires frequently broke, and the broken ends stuck outwards to the danger of the sailors handling the rigging; and to prevent accidents they were served with yarn, like the "selvagee" rope, after having been "wormed", that is having a yarn laid in between each strand so as to alter the shape to a round form.

The "formed" wire ropes were originally made on the rope ground by the forming machine usually employed in hemp rope making, shown in Fig. 7, Plate 48. The wires were wound on bobbins placed in racks, just like the hemp yarns, and were led through the perforated register plate, called the "minor" plate, thence through the taper steel nipper or compressing tube, and were attached to the forming machine, which drew out the wires and twisted them together as it travelled backwards towards the other end of the ground. Having arrived there the machine was stopped, and the length of strand thus made was wound upon a large reel, ready to be placed in the laying machine; the use of the reel also enabled a longer length of strand to be made than one length of the ground. For laying the strands into rope, the required number of reels of strand, generally four, were placed in frames mounted on horizontal bearings and geared together. The strands were stretched along the rope ground, being supported and separated on trestles placed at intervals; and were brought together over a "laying top" at the other end of the ground, and attached to a revolving hook. Motion was given to the machine at one end with the four strand reels, and to the hook at the other end in the opposite direction, by means of a "fly rope" or endless driving rope, passing over whelp wheels

attached to the machine and the hook; the laying top was carried by a workman, who thus regulated the amount of lay or twist. Afterwards the laying top was mounted on a carriage which travelled on rails, and was drawn forwards by another endless rope, called the "ground" rope, which was worked by the machine. This arrangement had the effect of more effectually regulating the lay. "Formed" wire rope is now made in the ordinary vertical machine, which is supplied with extra frames for carrying a large number of bobbins; but for forming the strands the bobbin frames are fixed to the frame of the machine, and not revolving in it, and the wires are brought together through a perforated plate containing the required number of holes.

"Formed" wire ropes were at first well saturated with the solution before described; but afterwards galvanised wire was used for making them. The admiralty still continue to use the "formed" rope entirely, though little is now used elsewhere. "Formed" ropes made of copper wire were used largely in the navy as lightning conductors, the size of the wire being about No. 20 wire-gauge or 0·036 inch diameter, and the rope was made of four strands laid round a small copper wire core. Smaller ropes composed of iron and copper wire were also used as sash lines &c.

In another kind of wire rope, which was sometimes made on the machinery above described for the manufacture of "formed" rope, the strands were composed of hard wires, usually not exceeding six in number, laid around a core of hemp or wire; and these strands were again laid around a hemp core into a rope. But the objections caused by the rigidity of these ropes prevented any but small sizes being used for some years. Ultimately however these objections were overcome, and this construction has now almost entirely superseded the "formed" rope.

The first Flat wire ropes, made 26 years ago, shown in Figs. 29 and 30, Plate 57, were composed of from eight to twelve "formed" strands, with the twist alternately right and left handed, made of a number of fine wires usually about 18 or 20 wire-gauge or 0·050 to 0·036 inch diameter. These strands were placed in the position of the warp, in a loom of the ordinary form but greater strength, and were

woven together with a shoot of strong yarn. Very little twist was put into the strands, as the yarn when woven in kept them in form. These ropes were by no means durable, as the yarn soon wore out, especially at the edges; and their application was very limited.

Flat wire ropes were next made, about 25 years ago, of four or six "formed" ropes, each made of four strands "laid" very long, and alternately right and left handed; these were stretched together side by side and sewn through with six wires of No. 14 or 16 wire-gauge from side to side in a zigzag direction, as shown in Figs. 31 and 32, Plate 57. This was accomplished by carefully inserting a needle of dagger shape between the strands of the ropes, and so making a passage for the wires, which were carefully laid side by side. The round ropes thus bound together resembled the ordinary flat hemp rope in appearance. The process was tedious, on account of the care necessary to avoid penetrating the strands with the needle, which would do great injury to the rope. It was also important that the amount of "lay" or twist in all the ropes composing the flat rope should be exactly the same, otherwise the stretching could not be regular, and some of the strands were liable to be cut when the rope was set to work. With the machinery previously described perfect regularity could not be attained in this respect, and an unsatisfactory result was the consequence.

The next and last construction of wire rope, introduced about 24 years ago, is known as "Laid" rope, shown in Figs. 33 and 34, Plate 57, in which the strands were made of a few wires, seldom exceeding six, "laid" around a core of hemp or wire, the wires of the strand being entirely free from twist, each wire being simply "laid" in a spiral form without any twist in the wire itself, as shown in the diagram, Figs. 35 and 36, Plate 58. Six of these strands were again "laid" without "forehard" or additional twist into a rope, around a core generally of hemp. The size of wire usually varied with the size of the rope, as the total number of wires 36 was seldom varied. The wire was hard or unannealed; and by the system adopted in making, a uniform length was obtained with entire absence of twist. By this means the full strength of the wire was retained, and consequently the

rope produced was much stronger for the same weight. An increase in size is however caused by the introduction of the hemp cores, which amount to 1-7th of the entire bulk in the case of ropes with six strands of six wires each, the construction now usually adopted.

These "laid" wire ropes, though not so pliable or strong as "formed" ropes, possess many advantages, especially when employed as incline ropes, the hardness and increased size of the wire giving greatly increased durability; and as the prejudice against wire ropes had been partially removed by the introduction of the "formed" ropes, the present "laid" ropes soon began to be extensively used; and within the last few years, since the expiration of many patents formerly existing, the manufacture has increased to a remarkable extent. Wire strand has lately come into extensive use for fencing, very large quantities being exported for that purpose for the Indian railways.

Flat wire ropes also are now made with strands composed of hard wires "laid" together, instead of "formed" as previously, these strands being again "laid" into ropes without any "forehard" or additional twist, and the ropes are then stitched together as previously described. Lately instead of several wires laid side by side being used for stitching, three or four strands have been substituted, each strand containing three wires laid together; the advantage of which is that though several of the single wires may be worn through, the strand still holds the rope together; yet in neatness of appearance the single wires have the preference.

The machinery used in the manufacture of "laid" strands and ropes originally consisted of the ordinary machinery used on rope grounds for laying or closing hemp ropes, the machines at each end of the factory being speeded alike, as previously described.

The next form of machine adopted had simply one hook, mounted in bearings on a fixed frame, and driven by hand or power, to which all the wires composing the strands were attached; these were stretched along the ground, supported at intervals on trestles, till they reached the other end, where they were hooked on to swivels or "lopers". Attached to the lopers were cords passing over pulleys

and having weights suspended from them, so as to regulate the tension of each wire and also allow for the shrinkage of the rope in the process of making. When the hook was set in motion, the twist in each wire traversed the entire length of the wire, and escaped at the end by means of the "loper" or swivel. A perforated plate or "laying top" was used, carried by a workman along the ground, regulating the amount of "lay" or twist.

The next machine used, shown in Fig. 40, Plate 59, was a modification of Huddart's hemp rope laying machine, previously described and shown in Fig. 19, Plate 54. In these machines the operation went on continuously until the required length of strand or rope was made, giving rise to the name of "endless" machines; they were also called "vertical" machines, because the main frame carrying the spools revolves on a vertical axis. The first modification of this machine for making wire ropes consisted in altering the gearing for working the spool frames B, so that no additional twist or "forehard" was put in the wires as in the strands of hemp ropes, the pinions on the spool frames being now made of exactly the same diameter as the central dead wheel, as shown in the diagram, Fig. 38, Plate 58, causing the spool frames to make exactly one rotation on their axes for each revolution of the machine. Machines of this description were also made to work on a horizontal axis instead of a vertical one; and a balance weight was sometimes attached to each spool frame in the horizontal machines, which by its gravity prevented the spool from twisting the wire and rendered gearing unnecessary for the purpose; but the speed of these machines was limited in consequence.

The next form of machine was that known as a "compound" machine, for producing the entire rope finished at one operation; and may be described as consisting of six stranding machines, like that last described, all mounted on one large frame and revolving horizontally, the necessary motion being given to the machinery to lay the wires into strands and then the strands into rope, without producing any twist in the individual wires. This machine, though a mechanical success, was a commercial failure, and was soon abandoned for the simpler and cheaper plan of first making the strands and then laying them into ropes on separate machines.

Next some modification was made in the vertical machines, shown in Fig. 40, Plate 59, in the means of preventing twist of the wires during the laying, by employing a centre crank or eccentric and four outer cranks on the spool frames B, as shown in Fig. 40, and in the diagram Fig. 37, Plate 58; and also by substituting chain wheels and pitch chain, as shown in the diagram Fig. 39, Plate 58. Machines were constructed with 36 spools on the revolving frame, connected by cranks to the centre crank; and ropes were thus made with that or any smaller number of untwisted wires in each strand; but this description of rope was rarely used.

In all the vertical and horizontal endless machines that have now been described, all the spools were mounted in one set on a single large revolving table, thus revolving all in one plane; and during the process of laying, the whole weight of the material had to be carried round a circular track varying with the size of the machine from 10 to 40 feet, one revolution being necessary for every lay put into the strand or rope, the lay varying from 1 inch to 18 inches or more in pitch, according to the size of rope. Machines of this construction were therefore necessarily limited in their speed. Lately however machines have been constructed with the spools arranged in two sets of three each, on two tables one below or behind the other, the spools thus revolving in two planes; whereby a somewhat increased speed was attained, as the diameter of the revolving tables was reduced. Yet still the spool frames had to be carried round the common centre and caused to rotate on their own centres once for every lay.

The method of joining the lengths of wires was in the first instance by twisting the ends together: afterwards, in the manufacture of "laid" strands, by "tucking", that is cutting out the hemp core about 12 inches from the end of the wire that has run out, and inserting in its place the end of the new length of wire; the rest of the wires are then "laid" up on the new wire as a core for a length of 6 inches, when the new wire is brought out into its right place and the remaining 6 inches of the old wire passed in as the core, on which the laying is again continued till the end of the wire is reached; the proper hemp core is then replaced, and the process of laying resumed as before. Some manufacturers prefer to braze or weld the ends of

the wires together for joining the lengths, wire as small as No. 16 wire-gauge or 0·065 inch diameter being welded by experienced workmen by means of a common portable forge.

An improved construction of wire rope machine has subsequently been introduced, in which the bobbin frames and bobbins are placed one behind another, all in the axis of the revolving frame, and remain stationary in that position while the frame alone is made to revolve. By this machine a greatly increased speed is attained, and it is considered that better work is produced. The rate of production is also much increased, as much as 10,000 yards of strand having been made per day of ten hours, instead of only 2500 yards, the usual amount made by the ordinary form of machine.

This machine, the invention of Mr. Archibald Smith of London, is shown in Figs. 41 to 44, Plates 60, 61, and 62. Fig. 41, Plate 60, is a general side elevation of the entire length of the machine. Fig. 42, Plate 61, is a side elevation of one portion or compartment of the machine, to a larger scale and partly in section. Fig. 43, Plate 62, is a transverse section, and Fig. 44 an end elevation at the front end of the machine.

The bobbins A A, Fig. 41, Plate 60, are here all arranged in a horizontal line one behind another, in the axis of the revolving frame of the machine. The revolving frame is composed of a number of disc wheels C C, framed together by three long bolts D, Figs. 42 and 43, passing through holes near the edges of the discs and through strong iron distance tubes with collars at each end, which are all turned accurately to one length. Eight discs C C, Fig. 41, are thus framed together by the three bolts, and separated by the distance tubes, forming seven compartments of the machine, each containing a bobbin of wire A. The last disc at the back end of the machine forms part of a three-speed cone pulley E, by which the entire frame is made to revolve, being supported and steadied sideways at every alternate disc by the three rollers F, Fig. 43. The bobbin frames B B are centred in the revolving discs C, and have a weight G suspended from their underside, sufficient to overcome the friction of the bearings and prevent the bobbin frames from revolving with the machine.

The front end of each bobbin frame B, Fig. 42, Plate 61, has a hollow steel stud or "nipple" I, carefully bell-mouthed; and the back end has a solid stud H. Each stud works in a boss cast on the disc C, having a clear hole right through the centre for the wire to pass through; and the boss on the front side of the disc has a large gap J, for the wire to pass out from the centre. The wire from each bobbin A, shown by the strong black line, is drawn off through the bell-mouthed stud I and the centre of the disc C, and is then taken round the leading pulley K, Figs. 42 and 43, which is fixed on the framing bolt D for the purpose of enabling the wire to clear the bobbin in the next compartment. The wires pass through holes in the discs C on either side of the framing bolts D, as seen in Fig. 43; and on reaching the front compartment of the machine, all the six wires from the six bobbins A, Fig. 41, are led round three pairs of leading pulleys K, and thence through the holes in the front disc, Fig. 44, through the laying plate L, Fig. 41, and over the laying top M. The laying plate L is attached to the front disc of the machine, and has a slot in it for each wire to pass through. The laying top M fixed in front of the laying plate is simply a cast iron block with the required number of scores or grooves for the wires. The front bobbin N, Fig. 41, in the first compartment of the machine, carries a seventh wire to form the core for the six external wires, which is led off through the centre of the front disc and through a hole in the centre of the laying plate L and laying top M. The tension or "temper" of each of the seven wires is regulated to the exact amount required by a friction break O on the spindle of each bobbin, Fig. 43, Plate 62. The bearings of the spindle in the bobbin frame B are provided with spring caps, to facilitate changing the bobbins.

The six wires are all brought together at a point immediately in front of the laying top M, Fig. 41, Plate 60, where they are all laid round the core by the revolution of the machine, the bobbins A remaining stationary with the exception of their unwinding motion as the wires are drawn off; each wire is thus laid into the strand free from twist in itself. The strand thus made passes between the nipping rollers P, Fig. 44, which have a series of scores of different diameters to suit various sizes of strand or rope; the lower roller turns on

a fixed stud, and the upper one on a weighted lever. The strand is then led half round the indicator sheave R, Fig. 41, which has a counter attached to indicate the number of yards or fathoms made. Thence it passes backwards alongside the machine to the draw-off wheels S S at the back end; these are V grooved wheels of equal diameter, round which the strand passes in a figure of 8 course, as seen in Fig. 41, being pressed tight into the groove of the second wheel by the tightening roller or jockey wheel T, which prevents the strand from slipping from any accidental cause. The draw-off wheels S are driven from the driving pulley E by intermediate bevil gearing, with a change wheel by which the speed of the draw-off wheels is regulated in proportion to the speed of revolution of the machine, whereby the lay of the wires or pitch of the spiral in the strand is determined. The strand finally leaving the machine from the draw-off wheels is wound on a bobbin, ready to be placed in a second similar machine to be laid into rope. In this second machine the revolution of the laying apparatus is in the opposite direction while that of the draw-off wheels is in the same direction as in the first machine, in order to make the lay of the strands in the rope contrary to that of the wires in each strand. From the second machine the rope is coiled on a reel, or in case of its being a long length it is sometimes coiled down direct into railway trucks &c. for transportation.

In this machine, instead of the bobbins and bobbin frames, which sometimes contain half a ton weight each, being carried round the common centre of the machine, sometimes describing a circle of 15 feet diameter, and also rotating on the axes of the bobbin frames once for every lay in the rope, the same result is attained without any motion being given to the bobbin frames. This is an important advantage, because in course of working some of the bobbins are full while others are nearly empty, and in the case of the old machinery a great strain is thereby thrown on the parts of the machine from the variation in weight; while in the construction just described the equilibrium of the machine is never disturbed. In addition to this, great regularity of lay results from the wire being free to unwind, and from the absence of the extra tension that was necessary to prevent the wire being disturbed when rapidly carried round in the old machine. The stationary position of

the bobbins enables the workman to see what is going on, and no entanglement of the wire takes place as is frequently the case in other machines.

About 35,000 miles of the covering strands of the Atlantic telegraph cable were made in this machine; and likewise about 14,000 miles of the hemp-covered strands of the Toulon and Algiers cable. It is also extensively used in the manufacture of wire ropes.

Steel wires are now extensively used in the manufacture of wire ropes, being found to possess twice the strength of the best charcoal iron wire; while the skin of the wire is of such remarkable hardness as to resist a very great amount of friction, and the wire has a toughness equal to that of copper. A compound hemp rope is also now made by inserting a wire in the centre of each yarn, and making these yarns up as an ordinary hemp rope.

A number of specimens of hemp and wire ropes were exhibited, illustrating the several constructions described in the paper; and also working models of some of the rope making machines, lent for the occasion from the South Kensington Museum. A working model was also exhibited and shown in action of Smith's wire rope machine described in the paper.

Mr. Shelley thought it was highly important that the reasons should be ascertained which led to hand making being reverted to in the manufacture of hemp ropes, in place of the beautiful machinery invented for the purpose by Capt. Huddart and used for some time in Deptford dockyard; he had been unable himself to ascertain why the

machinery had been given up, or what were the exact defects experienced with it. The basis of all the machines, both for hemp and wire ropes, seemed to be Mr. Cartwright's cordelier invented at the end of the last century.

Mr. B. Fothergill believed that one reason of the want of success of the machines for the manufacture of hemp ropes was a defect in the preparation of the material by the machinery, which did not produce a uniform thickness of thread; and the want of uniformity of thread resulted in unevenness of the strands made from the yarns, and consequent unevenness in the ropes themselves. Also wherever there was a small part in the thread, the twist all ran into that particular place, and the thicker parts of the thread did not get twisted enough; so that when a strain came upon the rope, the thicker parts of the threads gave way and were drawn out and the strain was all left to be borne by the smaller parts, and breakage was the consequence. Another defect in the machines was that no provision was made for laying exactly the same length of yarn upon each bobbin: this might readily be done by a measuring apparatus such as was ordinarily applied in cotton machinery, and then the bobbins would all be empty at the same time, and there would not be a heavy full bobbin on one side of the revolving frame of the machine and a light empty one on the other. In some hemp rope machines also there had been a defect in the arrangement for giving uniform motion to the twisting of the different strands when they were being laid into the rope. He thought the paper that had been read was one of a very interesting and instructive character: with regard to the manufacture of wire rope, he believed the hand method which formed the basis of the manufacture had its origin in the Hartz mountains.

Mr. A. Smith remarked that in wire rope machines the inequality of weight arising from full and empty bobbins on opposite sides of the stranding machines was inevitable in the previous constructions of machines; for the wire was necessarily supplied to the machines in bobbins which would not contain the whole length of wire required for the entire strand, and it would be very unwise to let all the bobbins empty at once and all the joints come at one part of the strand. The bobbins therefore inevitably emptied at different times in the stranding

machines; but in the rope machines they all emptied simultaneously, since each bobbin contained the exact length of strand required for the whole length of rope.

Mr. Shelley enquired whether the defects that had been mentioned in the manufacture of hemp ropes had been overcome in the machine shown in the American department of the Exhibition, where the yarns were taken in at one end and twisted into strands, and the strands were then laid into a rope which came out at the other end of the machine. This machine was now at work, making ropes of half an inch diameter.

Mr. B. Fothergill said the defects he had mentioned were not entirely overcome in the machine referred to; but the main defects lay in the preparation of the material before it was spun into yarns. In the treatment of flax or cotton the raw material was first got into a slivered form, and was then passed through a series of rollers, taking care not to destroy the fibres, but to draw and lay them parallel side by side; and in order to get uniformity of thread in spinning, the fibres so drawn out were then doubled again and again as many as twelve or thirteen times in the case of fine cotton spinning. Without this doubling it was impossible to obtain uniformity in the thread, and the defect that he had referred to in the manufacture of the threads for hemp ropes arose from the want of a sufficient number of doublings, so that in spinning the yarns there was a want of uniformity in the thickness; and in forming the strands these yarns were only congregated together, whether thick or thin, in a sufficient number for the required size of strand. The only approach to doubling was the twisting together of the yarns into the strand; but the doubling ought to take place in the raw material, so as to secure a uniform thickness of thread, and then the ropes would no doubt stand a much greater tension.

Mr. F. J. Bramwell remarked that in 1853 he had seen some hemp rope machinery at the Boston dockyard in America, where there was an arrangement in the preparing machine to equalise the amount of material taken in, by producing a retardation to prevent thick parts occurring in the thread; this was found to work well, and he had thought the difficulty on that score had been thereby overcome.

Mr. J. Fletcher observed that he had lately seen some new machinery which was now being tried at Chatham dockyard for the purpose of ascertaining the difference of strength and pliability between hand and machine-made rope, made from the same hemp: and he understood the result already arrived at was that the machine-made rope was superior to the hand-made. In the manufacture of the machine-made rope the doubling system was adopted: six slivers of hemp were passed together through rollers, and two of these rollings were twisted together and spun into one small thread, and a strand was composed of a number of these threads twisted together.

The Chairman enquired whether the comparison of the hand and machine-made ropes was made weight for weight: and also what was the relative quantity of tar that was held by each construction of rope.

Mr. J. Fletcher replied that the comparison of the ropes was made weight for weight and girth for girth; but the ropes were dry and no tar was used in them. He was not able to state the exact results arrived at with regard to the superiority of the machine-made ropes, but understood the general result was decidedly in their favour.

Mr. P. Haggie remarked that he had found in the manufacture of hemp ropes that in the preparation of the hemp the less it was passed through the rollers and doubled the better, if only the fibres were got something like straight and parallel: for after about the third time of doubling and passing through the rolling machine the gummy part of the fibre seemed to be destroyed by further manipulation, and although the fibres might be got more parallel, the yarn spun from the hemp was not so strong as when the hemp underwent less preparation. At his own works they had experimented a good deal upon the difference between hand work and machine work, and found that machine-made rope was about 25 per cent. stronger than hand-made rope of the same girth. The government test for yarn was 8 stone or 1 cwt. for a single yarn of the common size No. 18; but out of the same hemp machine-made yarn of the same size would bear from 12 to 18 stone; and he hoped they would ultimately be able to ensure a definite strength in all ropes of a given size and material. In

collieries, where machinery had often to be lowered into the pits and men's lives were dependent on the strength of the rope, it was particularly important to be able to rely on a certain definite strength throughout the entire rope.

Mr. B. Fothergill observed that, with regard to the preparation of the hemp fibres, the doubling of the material was perhaps a point of less importance than that care should be taken to avoid breaking the fibres in the process of laying them side by side: if the doubling were too frequent or if the several pairs of rollers were not at the right distance apart from one another, the fibre would be broken. The importance of treating the fibre in the right way to begin with might be understood from the fact that Heilmann's combing machine, which combed the fibres and laid them parallel without breaking them, had in the course of only five or six years become extensively applied to cotton, wool, and flax; and in the case of cotton a better yarn was produced by the use of this machine out of cotton that was *6d.* or *7d.* per lb. cheaper than that required under the old method of carding. A series of these machines also selected the fibres according to their length, and he had known as many as fourteen different lengths of fibres got out of one sample of material; of these the longest could then be taken for the best class of work, and the shorter lengths for inferior work. If care were taken that the fibres thus combed and laid parallel should not be broken in the after treatment of the material, so as to maintain their length and uniformity, the yarns spun from such a sliver would be five or six times as strong as under the old mode of preparing the fibres.

Mr. E. A. Cowper remarked that at Portsmouth dockyard which he had lately visited scarcely any machinery was used for rope making, steam power being employed only to turn the spindles of the ordinary hand machines. There appeared to be a strong prejudice against machine-made hemp rope, which was said to be deficient in strength. He was glad to learn however that at Chatham attention was now being paid to the subject, for he was satisfied that hemp ropes could be thoroughly well made by machinery, and that more strength could be got with hemp rope properly made by machinery than with hand-made rope of the same size.

The CHAIRMAN enquired what was the reason why Capt. Huddart's machinery was discarded at the dockyard, if other manufacturers had found the machine-made ropes could be made so superior to hand work; and whether the machinery was still in use at any other of the dockyards.

Mr. E. A. COWPER replied that Capt. Huddart's machinery was used for upwards of forty years at the Deptford dockyard, but at the end of that time the government pulled it down and it was bought by Huddart's firm, and it was not now used in any of the government dockyards: but he had not been able to ascertain the reason why it was given up there, when the use of machinery had been found so advantageous elsewhere.

Mr. P. HAGGIE said that some years ago his works were visited by some government officials for the purpose of testing some government hand-made ropes with his machinery; and he had since learnt that they found the manufacture of the hemp ropes as carried on by machinery at the works was much superior to the old plan of hand work in the government yards; but there the matter was allowed to drop, and the question had been shelved ever since. With regard to the plan of repeated rolling with a succession of rollers in preparing the hemp for spinning, he believed that method would not apply to long fibres such as those of hemp, the ordinary length of which was from 5 to 6 feet, and therefore there was no other way of dealing with the hemp but that which they adopted of getting the fibres as nearly straight as possible, with the least possible drawing, so as to get the greatest amount of strength out of the hemp.

Mr. E. A. COWPER observed that in passing the hemp through the drawing rollers the distance between the successive pairs of rollers must of course be arranged according to the length of the fibres, in order that the fibres might not be broken in the machine: and the same precaution had to be observed, whatever was the material undergoing preparation.

Mr. F. JENKIN remarked that in the new horizontal wire rope machine now described the wire appeared to undergo a considerable amount of bending in its course from the bobbin to the laying plate, each wire being bent on all sides successively during each revolution of

the machine in passing through the hollow nipple in the centre of the revolving disc, becoming thus crimped into a wavy form with a length of wave corresponding to the length of lay of the strand. This might not be of any importance in the case of small wires, but in large wires he thought it would be a serious defect to bend the wire in this manner; and he enquired whether any of the machines had been applied to laying large wire into strands.

Mr. A. Smith explained that the bending of the wire previous to its arrival at the point of laying was not peculiar to the new machine, but was common to the previous vertical machines also: it was only more apparent in the horizontal machine, because the length of the machine was there so great that it was desirable to shorten it as much as practicable by increasing the angle of bending. But so long as the bending of the wire between the bobbin and the point of laying was less than the bending it received in being laid into the strand, no harm was done, whether the wire were thick or thin: had it been of importance to avoid bending the wire more than necessary, the machine might have been lengthened to the required extent for the purpose. The new machine had been applied to large wire as thick as No. 4 wire-gauge or 0·240 inch thick, without any injury to the wire; and it had been adopted and successfully employed by Messrs. Glass Elliot and Co., for laying on the covering wires for protecting the shore ends of telegraph cables.

Mr. T. Snowdon asked whether the wire was bent so much as to cause it to scale.

Mr. A. Smith replied that it was never bent to such an extent as to throw off a scale.

Mr. J. Fletcher remarked that no harm could be done to the wire if the bending in the machine were less than that which it had upon the bobbin.

Mr. P. Haggie observed that the strength of steel wire had been stated in the paper to be twice that of the best charcoal iron wire, but his own experience was that the best steel wire was only 50 per cent. stronger than charcoal iron wire, while the common run of steel wire was not more than 10 per cent. stronger than iron, and some steel wire was not even equal in strength to iron. It was also a question

of great importance how to prevent steel wire as well as iron wire from becoming brittle in work: the wire seemed to change its character and become crystallised by the friction the rope was exposed to in passing over a series of pulleys, and in a few months' time the rope became quite brittle. The process of crystallisation was slower in iron wire than in such steel wire as had hitherto been made for the purpose of wire ropes.

The CHAIRMAN enquired what had been found to be the actual strength of ropes made of charcoal iron wire.

Mr. P. HAGGIE replied that he had lately tested an iron wire rope of about $1\frac{1}{16}$ inch diameter, which had been in use three months, and it bore 18¾ tons before breaking; it was a "formed" rope of six strands, each strand being "formed" of 19 wires twisted together, of No. 16 wire-gauge or 0·065 inch thickness, so that the whole rope contained 114 wires or 0·378 square inch section of iron, giving a breaking strength of 50 tons per square inch. This rope had been damaged by an accident, and was tested for the purpose of ascertaining its strength in the uninjured part.

Mr. SHELLEY asked what size of hemp rope would be required to bear the same weight as the wire rope, and what would be the respective weights of the two ropes.

Mr. P. HAGGIE replied that an 8 inch hemp rope would be required to bear the same load of 18¾ tons before breaking, that is a hemp rope of 8 inches circumference or rather more than 2½ inches diameter, or else a flat hemp rope 4½ inches broad composed of four smaller ropes: the last hemp rope that he tested of about that size, 8½ inches circumference, broke at 28 tons, but that was an extreme case. The weight of the hemp rope was about 1⅗ times that of the wire rope of the same total strength; for the 8 inch hemp rope weighed 16 lbs. per fathom, while the wire rope was 10 lbs. per fathom.

Mr. A. SMITH said that as regarded the relative strength of steel and iron wire the statement in the paper was founded upon a number of experiments that he had witnessed, from which it appeared that 500 lbs. was a very fair breaking test for charcoal iron wire of No. 14 wire-gauge or 0·085 inch thickness, amounting to 40 tons per square inch section of metal; while he had seen steel wires of the same gauge,

of a superior manufacture, bear 1000 and even 1100 lbs., or 80 to 90 tons per square inch. He thought it was generally admitted that ordinary steel wire made for wire ropes would bear nearly double the strain of iron wire of the same gauge, the generally received proportion being 7 to 4. Fowler's steam plough afforded a good instance in which fine steel wire ropes were used with advantage, from their superior strength and lightness as compared with iron wire ropes: and he had also heard of a valuable application of steel wire rope in France for transmitting power to half a mile distance; in this case the ropes used were very light, only about 5-16ths or 3-8ths inch diameter, and were driven at a very high velocity.

Mr. E. A. Cowper observed that some experiments which he had made on the strength of Webster and Horsfall's hard steel music wire gave the ordinary breaking strength at about 85 tons per square inch. In one case of very hard wire the breaking weight was found to be as high as 130 tons per square inch, but this wire was rather too hard for use.

Mr. P. Haggie said the highest result he had obtained with steel wire rope was in a rope of 3½ inches girth which he had just tested, made of the best quality of wire, which broke at 35½ tons; while an iron wire rope of the same size would break at about 22½ tons. But this seemed an exceptional case, for in other steel wire ropes which he had tried of the same size the highest breaking strain was only 22½ tons: and he had found a single bundle of steel wire contain so many varieties of temper that the objections against the use of steel wire ropes appeared more serious than those which had been urged against machine-made hemp ropes from irregularity in the spinning of the yarns.

The Chairman enquired what would be the strength of a hemp rope of the same size, and what was the relative durability and cost of hemp and wire ropes of the same strength.

Mr. P. Haggie replied that a hemp rope of 3½ inches girth would not bear more than about 3½ or 4 tons. But in comparing hemp and wire ropes of the same strength he believed that if the same attention were bestowed upon the hemp rope as upon a wire rope the hemp rope would be found more economical in durability as well as in first cost,

provided the depth of the pit were not extreme. Beyond a certain limit indeed a hemp rope used for winding in a pit would kill itself; that is the great weight of the rope itself hanging down the pit and the consequent continued stretching every time it was lowered would eventually cause it to become almost rotten, and it would then give way.

The CHAIRMAN hoped Mr. Haggie would give the results of his experiments on the strength of hemp and wire ropes in the form of a paper at a future meeting of the Institution. He proposed a vote of thanks, which was passed, to Mr. Shelley and also to Mr. Smith, for the information communicated in the paper that had been read, and the numerous interesting models and specimens by which it was illustrated.

The Meeting was then adjourned to the following day. In the afternoon the Members visited the Government Small Arms Factory at Enfield.

The Adjourned MEETING of the Members was held in the Lecture Theatre of the Royal Institution, Albemarle Street, London, on Thursday, 3rd July, 1862; Sir WILLIAM G. ARMSTRONG, President, in the Chair.

The following paper, communicated through Mr. Charles P. B. Shelley of London, was read:—

ON THE CONSTRUCTION OF SUBMARINE TELEGRAPH CABLES.

BY MR. FLEEMING JENKIN, OF LONDON.

The Submarine Telegraph Cables that are now in successful operation are nearly all of one general construction; and this description of cable will be first referred to in the present paper. The only essential parts of a submarine telegraph cable are: first, a conductor along which the electricity may flow from one station to another; and second, an insulator surrounding the conductor and separating it entirely from the sea. In the common cable a wire or strand of copper forms the conductor, which is covered and insulated by gutta-percha. This core of gutta-percha covered wire is served with tarred yarn, round which a greater or less number of iron wires are laid spirally, to afford longitudinal strength and lateral protection.

A cable of this class is shown in Figs. 1, 2, and 3, Plate 63, which represent the Malta and Alexandria telegraph cable, laid in 1861, drawn double full size: the copper conducting core A, Fig. 3, is shown black in section, and is surrounded by three coatings of the insulating gutta-percha B. Copper is used for the conductor because it resists the passage of electricity less than any other available metal, whereby a greater number of words per minute can in a submarine cable be sent through a copper wire than through an iron or steel conducting wire of the same dimensions and placed in the same circumstances. Different specimens of copper vary greatly in their resistance; some commercial copper has in this respect only 14 per cent. of the value of chemically pure copper, or is 86 per cent. inferior to the latter, which however cannot be practically obtained in commerce. The course followed by the principal manufacturers of telegraph cables is to select by an electrical test the wire best suited to their purpose; and this wire is about 20 per cent. inferior in conducting power to pure copper.

A solid wire would be preferable electrically to a strand, for the same reason that copper of small electrical resistance is preferable to copper of high resistance, the object being in all cases to obtain the greatest conducting power within a given circumference. The interstices in the strand diminish the conducting power for a given size, and the gutta-percha sheath must be of proportionately larger diameter to give the same speed of transmission and the same insulation as when a solid core of equal weight is used. When large conductors are required however a solid wire is not found flexible enough; and moreover a single copper wire is found liable to break inside the gutta-percha, without any external symptom of injury being seen: for these reasons a strand is almost universally adopted for large cores.

In the cables first made, the interstices between the wires of the strand were left vacant; but it was found that under continued pressure the water invariably penetrated into these vacant spaces and percolated along them. This was thought dangerous for various reasons, and therefore the Gutta-Percha Company now lay up their strand in an insulating compound called "Chatterton's compound," consisting of gutta-percha and resinous substances, which so completely fills the spaces that a pressure of 600 lbs. per square inch cannot force a single drop of water six inches along the finished core: other makers have adopted the same plan. The cables shown in Figs. 1, 2, and 12, Plates 63 and 66, have this compound between the wires of the strand; while the Red Sea cable, Fig. 7, Plate 64, and several earlier cables are without it.

In reference to the electrical conditions determining the best dimensions of the conductor and its insulator, it is sufficient here to observe, first, that for every given ratio between the cost of the materials of the insulator and of the conductor there exists a corresponding ratio between the diameters of the conductor and insulator which will give the maximum efficiency at a minimum cost; and practically the thickness of the gutta-percha is almost always in excess of this theoretical thickness. Secondly, if a constant ratio is maintained between the diameters of the conductor and insulator, the number of words per minute which can be sent through a given length

of core is simply proportional to the quantity of the materials used; so that a core to transmit twenty words per minute will weigh four times as much and cost about four times as much as a core to transmit only five words per minute.

The manufacture of the copper conducting strand is extremely simple. Owing to the soft nature of the metal, it seems to be of little importance whether the wire is twisted in making the strand or not; although in the outer iron sheathing of the cable it is of special importance for the wires to be "laid" without twist. In the diagram, Fig. 18, Plate 67, is shown a simple form of strand machine, and the twist of the wires is shown by the direction of the arrows upon the four bobbins. A friction break restrains the movement of each bobbin, and is adjusted by hand until the spinner feels that the tension of each wire is equal. The drums of the bobbins are made large in proportion to their total diameter when full of wire, so that the leverage of the break does not vary rapidly during the unwinding of the wire. It is important that every wire of the strand should be put in with a constant and equal strain, otherwise one wire will sometimes ruck up during the subsequent covering process, and knuckle through the insulating covering. Each length of wire is soldered to the next length, so that there may be no loose ends which might come through the gutta-percha. Where one piece of strand is joined to the next, a scarf joint is made, lapped round with binding wire and neatly soldered.

In covering the strand the gutta-percha is applied in a plastic state, in successive coatings over the strand, which is for this purpose drawn through a series of dies, each one in succession larger than the preceding. Between the several layers of gutta-percha a coating of Chatterton's compound is laid on in the Malta and Alexandria and other cables, as indicated by the strong black lines in Figs. 1, 2, 7, 8, 9, 10, and 12, Plates 63 to 66; but the Atlantic cable, Fig. 6, and the other cables shown in Figs. 4, 5, 11, and 13, are represented with a solid covering of gutta-percha, because no Chatterton's compound was here used between the several layers of gutta-percha. The Red Sea cable, Fig. 7, Plate 64, and several earlier cables had the

compound between the coats of gutta-percha, though not between the wires of the copper strand; the latest cables have both.

When india-rubber is employed as the covering it is applied in strips wound spirally round the strand in most cases; but it is put on longitudinally in the plan invented by Mr. Siemens, and described at a former meeting (see Proceedings Inst. M. E., 1860, page 137). Solvents were at one time used to joint the strips of india-rubber, but they are now generally cemented into a solid mass by heat applied in various ways. But in Mr. Siemens' plan the simple contact under pressure of freshly cut surfaces of india-rubber is said to be sufficient to join the longitudinal strips without the use of extra heat or solvents.

The question of the relative merits of the two materials, gutta-percha and india-rubber, for the covering of telegraph cables, is one of much practical interest. Gutta-percha sometimes contains impurities, and air bubbles were at one time not uncommon in the covering with that material; these air bubbles and impurities become serious faults under the action of powerful electric currents. Gutta-percha becomes plastic at about 100° Fahr., and the copper wire sometimes forces its way through the insulating sheath when the gutta-percha is accidentally softened by heat; moreover joints unskilfully made are liable to decay in time. On the other hand the merits of gutta-percha are very great. Not a single yard of submerged gutta-percha has ever decayed; and the importance of this fact after the experience of many years on some thousands of miles of wire can hardly be over-estimated. No gutta-percha cable has ever failed except from local imperfection or accidental injury; two causes of failure to which all known materials must be subject. The insulating properties of gutta-percha as now supplied are extremely good. No known material insulates perfectly; but if 2000 miles of the same gutta-percha covered core that was supplied for the Malta and Alexandria cable, perhaps the best yet constructed, were laid say across the Atlantic ocean, and were maintained at the very improbable and disadvantageous temperature of 75° Fahr., the current received through that cable would amount to 97¾ per cent. of the current

which would be received through a cable with absolutely perfect insulation. Roughly speaking it may be said therefore that the insulation of that cable was for a length of 2000 miles within 2½ per cent. of perfection. Further improvements in insulation may be effected, but they are really of no practical importance, since they can only affect the very trifling difference between absolute perfection and the high degree of insulation already attained: and in the author's opinion no increased cost would be justified for obtaining any further increase in the insulation of the wire. Sound gutta-percha covered wire may therefore be considered practically perfect in insulation, and well made joints are as good as any other part of the core.

It may be remarked here that the word "insulation" has frequently been used in a double sense: first, as implying freedom from mechanical defect or impurity; and secondly, as implying electrical resistance. Consequently some statements that are true when the word is used in one sense have been incorrectly applied with the word in the other sense, causing some confusion in the comparisons of gutta-percha and india-rubber. Thus the circumstance that india-rubber is a better insulator in consequence of having a higher electrical resistance than gutta-percha has in mistake been incorrectly taken to mean that india-rubber is the better material for covering telegraph cables; whereas the words "better insulator" imply properly in this case a superiority in the one respect of non-conducting power alone, and not a general superiority in all respects.

The defects of india-rubber differ with different makes: some kinds are liable to turn into a treacly substance on the outer surface and next to the copper; others are liable to little cracks or fissures which appear only after the cable has been manufactured for some time; and other kinds turn slimy in water, arising it is said from a considerable absorption of water. The cause of these defects does not seem well understood, and various reasons have been assigned by different makers: such as injury of the india-rubber from heat applied to make the joint, or injury from the strain put on the india-rubber strips as they are wound on; defective structure arising in the preliminary mastication of the material in its preparation; or some

injurious effect of the contact with the copper. Exposure to light and air is also generally allowed to be injurious; but in the author's opinion the real causes of failure in india-rubber covered cables must be considered not yet satisfactorily ascertained. One defect is common to all forms of india-rubber covering, namely the necessary difficulty of making the continuous joint which is required along the whole wire; and another defect common to all forms of non-vulcanised india-rubber is the liability to injury from grease or oil. The latter danger is of the most insidious kind, for the injury is not immediately apparent, but requires a long time for its full development.

The merits of india-rubber however are not to be passed over lightly, and if they do not justify its general adoption as yet, they certainly entitle it to all the attention it has received for the manufacture of telegraph cables. When properly prepared it is an excellent insulator in the limited electrical sense of the word; whether better or worse than the present gutta-percha does not much matter, as has been shown above. It maintains its insulation better at high temperatures than gutta-percha, and will bear a higher temperature without permanent injury; it has also been thought by some less liable to mechanical injury than gutta-percha. But by far the most important point claimed in its favour is that a greater number of words per minute can be transmitted through a wire covered with india-rubber than through the same wire covered with the same quantity of gutta-percha of the usual quality. There is reason to believe that in this respect india-rubber is twice as good as any gutta-percha hitherto practically supplied for cables; but a few specimens of gutta-percha have certainly been manufactured which even in this respect are on a par with the best makes of india-rubber. An endeavour has been made by Mr. Siemens to obviate the defects and retain some of the advantages of india-rubber by protecting it inside with Chatterton's compound and outside with gutta-percha. The core of Mr. Siemens' cable, shown in Fig. 15, Plate 67, is covered in this manner, E being the india-rubber covering, with a coating of gutta-percha B outside, and a layer of Chatterton's compound F inside, covering the wire strand A: in this case the copper strand is made up more nearly to a circular form by the

addition of six small wires placed in the grooves between the six external wires of the strand, as shown in the enlarged section of the core, Fig. 17, drawn six times full size.

The main practical question still is, which material offers the best chance of permanency; and at present in the writer's opinion the answer must be in favour of gutta-percha, which is supported by the fact that the old telegraph companies continue to employ gutta-percha for their new cables.

The serving with hemp or jute yarns C, Fig. 3, Plate 63, as practised at present, is done by machines similar to those strand machines which put a twist into the wire or yarn; and advantage is taken of the flexibility of the yarn to place the bobbins in any convenient position. A large number of yarns are used, put on with a long twist or pitch, in order to avoid any chance of bending or twisting the core if one yarn breaks or is not so taut as the others. The serving merits more attention in the author's opinion than it has received, and he considers that many machines for manufacturing telegraph cables still put too much strain upon the core, especially when it is small and weak; and that the hemp might be applied so as to protect and strengthen the core much more effectually than is now the case, and thus form a much better preparation than is now afforded for the final process of sheathing with iron wires. The usual cores, both before and after they are served with the yarn, are very weak and liable to be stretched if any hitch occurs in the feed of the machines; and the author believes that several mishaps might be traced to this cause, and that the construction of a thoroughly good serving machine is a desideratum of much importance. The yarn protected by wires remains sound under water for a long time.

The final process of sheathing the cable with iron wire D, Fig. 3, Plate 63, is similar to that of making wire rope; and the machines used for the one purpose answer for the other, with the simple addition of a guide for the central soft served core. All the machines used "lay" the wire without twisting it, the same as in the manufacture of wire ropes.

Only the commonest form of submarine cable, Fig. 1, Plate 63, has hitherto been described, consisting of one insulated conductor served with hemp and protected by iron wires laid round it. A description will now be given of some of the other forms that have been used or proposed.

Instead of one gutta-percha covered core, several separately insulated wires are frequently included in one sheath, as shown in Fig. 4, Plate 64, which represents a cable of this class laid in 1854 between Spezzia and Corsica. This cable and all the subsequent ones are shown double full size in the engravings. This cable has six insulated conductors, which are all now in working order; and the cable has not cost anything for repairs since first laid, and is still in constant work. The several insulated wires in this and similar cables are coated with gutta-percha, and then laid up with hemp worming into a strand by laying machines similar in general arrangement to those for sheathing. The gutta-percha covered wire is of course not twisted, but the hemp generally is. The cables across the English Channel are generally of this class.

In the Atlantic telegraph cable, shown in Fig. 6, Plate 64, laid in 1857, the simple iron wires of the sheath were replaced by small strands, made each of seven wires of 0·028 inch diameter; but these were found objectionable on account of their rapid corrosion.

Strands formed of thick wire are however frequently used to cover heavy shore ends of telegraph cables, and are almost necessary in the largest cables for giving sufficient flexibility. In Figs. 9 and 10, Plate 65, is represented the Holland cable about to be laid, the shore end of which, Fig. 10, weighs 19·6 tons per nautical mile; the external protecting wire is here 0·220 inch diameter in the strands covering the shore end, while the single wires covering the main cable are 0·375 inch diameter, Fig. 9; but in the process of manufacture the cable was wound round a 7 feet drum without difficulty.

In the Toulon and Algiers cable, Fig. 8, Plate 64, laid in 1860, the iron wires of the sheath were replaced by steel wires, 0·085 inch diameter, each covered by a tarred hempen strand. This form though convenient in many ways has been abandoned, because the marine insects eat away the hemp with great rapidity, leaving a mere bundle

of loose wires. Simple hempen coverings have also been proposed, and in a few instances unsuccessfully tried.

A single copper wire however, 0·065 inch diameter, merely covered with gutta-percha, Fig. 5, Plate 64, was laid successfully between Varna and Balaclava in 1855, during the Crimean war, a distance of 300 miles, and worked for about nine months.

In a construction of telegraph cable proposed by Mr. Allan, no outer covering of wires is used, but the gutta-percha covered wire is strengthened by a layer of small steel wires round the copper conductor, as shown in Figs. 13 and 14, Plate 66. It is doubtful whether this plan is preferable to a simple copper strand covered with gutta-percha; though superior mechanically, it is far inferior electrically.

The rapid corrosion of the outer wires in some situations when submerged is perhaps the chief defect of the common type of submarine cable. To prevent this corrosion the Isle of Man cable, shown in Fig. 11, Plate 66, and the Wexford cable had a bituminous compound applied over the iron wires on Mr. Latimer Clark's plan. The Isle of Man cable was passed through the hot melted compound, and was considered to have been injured in some places by having been accidentally delayed in its passage through the hot material. The Wexford cable was not passed through the melted mass, but had the compound thrown over it or basted on, and by this simple contrivance a very serious danger was avoided. This plan of preventing the decay of the iron wires is fast coming into favour.

As a protection against rust it has also been proposed to cover each of the outer wires separately with gutta-percha. A cable of this make, shown in Fig. 12, Plate 66, with strands composed of three iron wires instead of single wires in the sheath, was suggested by Mr. Chatterton for the new Atlantic line, and except on the score of cost seems well adapted for the purpose. It has also been proposed to protect the iron wires by vulcanite, applied either as a general coating or to each wire separately.

In a plan introduced by Mr. Siemens, instead of protecting the iron wires they are omitted altogether, and another material considered more durable is substituted. This construction of cable is shown in

Figs. 15, 16, and 17, Plate 67. The core is surrounded with two layers of hempen strands CC, Fig. 15, laid on under considerable tension. Three or more strips of copper or brass GG, about 0·01 inch thick, are then bound round these strands while they are still stretched by the tension; and this copper or brass sheathing grips the hempen cords tightly, so that they cannot contract longitudinally after leaving the machine. By this construction a cable is obtained which is extremely light and strong; thus a cable ⅜ inch diameter bears a strain of 15 cwts. before breaking, and stretches only 0·8 per cent. of its length under a load of half the breaking strain. Mr. Siemens is of opinion that from the experience obtained from the sheathing of ships' bottoms, the copper or brass strips outside this cable will be far more durable than the iron wires of the usual cable; experience however with telegraph cables can alone finally decide this point, which admits of much discussion.

The machine used for sheathing the cable with the metal strips is shown in Figs. 19 and 20, Plate 68. Two serving machines are placed one behind the other, and are driven in opposite directions, laying on two distinct hemp coverings. The number of bobbins or the size of the strand in the two machines is so adjusted that each covering although of different diameter may have the same lay or pitch of the spiral. Each hemp strand passes round a V pulley between the bobbin and the laying plate, and an adjustable break is applied to each of these pulleys to strain or stretch the strands. A cable of ⅜ inch finished diameter has two layers of 16 hempen strands each, and each strand is laid on under a strain of 8 lbs. In front of the two serving machines and driven by a separate band stands the sheathing machine, Fig. 19. The copper or brass strips GG are wound on bobbins H, as in the usual serving machines; and are drawn off from the bobbins to certain guides of peculiar form close to the served core. These guides lead the several strips so that each strip laps over the preceding one by about one third of its breadth. The core is supported and compressed by the tightening nozzle II up to the very spot at which the metal strips are laid on. The nozzle I is made up of segments contracted by an adjusting screwed nut, a transverse section of which is shown one quarter full size in Fig. 21. The strips laid on lapping over one

another would form a cone instead of a cylinder, if it were not for a series of rollers JJ, between which the metal sheathed cable is immediately passed. These rollers forcibly compress the metal sheathing into a cylindrical shape; and a simple adjustment regulates the pressure exerted by all the rollers, as shown in the end elevation, Fig. 20, by means of circular inclined surfaces K pressing upon the ends of the slides that carry the rollers, which are all adjusted simultaneously by the hand wheel L. The result of the manufacture is certainly a cable very beautiful in appearance; its practical value can only be decided by experience, but in the author's opinion it is superior to any of the very light cables hitherto proposed.

The copper or brass sheathing affords lateral protection to the core; the longitudinal strength of the cable is amply sufficient both for the necessary strain during submergence, and to provide against accidental injury; and insects will not lodge in the hemp so long as the metal sheathing remains intact. There may be some ground for apprehension, in the author's opinion, as to the durability of the light copper or brass sheathing; but this must necessarily be left to be decided by further experience on a large scale.

In reference to the defects of the usual iron wire sheathing as shown in the drawings, it may be observed that some misconceptions have existed upon the subject. It seems to be generally supposed that wires laid on spirally round a soft core must, as soon as any strain comes upon them, stretch somewhat in the way that a spiral spring does; and many attempts have been made to obviate this supposed defect: but on actual trial no defect is observed. The single open helix of a spring stretches by diminishing the diameter of the coil; but when a number of wires are laid up touching one another, so as to form a solid ring or cylinder round a centre, as in a telegraph cable, the diameter of the ring cannot diminish, even though the centre of the cable is soft; and consequently the only stretching that occurs is due to the elongation of the iron itself, added to a very small constant due to the more perfect closing of the wires one against another. The following experiment on the stretching of telegraph cables is taken at random from a very large number made by the Board of

Trade Committee on submarine telegraph cables, all confirmatory of this view. The total section of iron in the Red Sea cable which was experimented upon, shown in Fig. 7, Plate 64, is about 1-10th square inch; and one sample 100 inches long elongated 0·56 per cent. with 75 cwts. strain; and it broke with 77½ cwts., or about 39 tons per square inch strain upon the iron wire. Other samples of the same cable elongated about 1 per cent. with 85 cwts. Then single iron wires of about the same size as those in the cable, 0·085 inch diameter, were found to stretch from 0·46 to 0·72 per cent. before breaking, and bore about 4·4 cwts. each, or 39 tons per square inch. It appears therefore from experiment that there is hardly any difference in elongation between a solid rod and a well laid up cable; and in strength no difference whatever between the cable and the wire composing it. The core does not, as at present made, add sensibly to the strength of the cable; for its resistance to the extension of say one per cent., at which the cable breaks, is insensible compared with that of the iron wire sheathing.

The twist put into a cable by the usual mode of coiling it when laid in a mass, as in the hold of a vessel, has also sometimes been misunderstood: a twist is no doubt put into the cable by the process of coiling, but this twist is as certainly taken out again when the cable is uncoiled, and is therefore of no importance.

The only inconvenience attending the spiral lay of the cable sheathing, in the author's opinion, is first apparent when the cable is being paid out, without sufficient strain upon it to lay it taut along the bottom. Then as the slack accumulates the cable becomes virtually free at the bottom, while the parts near the surface of the sea have considerable weight to bear; and the cable therefore untwists and throws itself over into a bight. The number of turns taken out of the cable, and of bights put into it along the bottom, depends simply on the amount of slack paid out. When the cable is again picked up, these bights draw tight into kinks, to the injury of the recovered cable; and this is the only practical inconvenience attending the usual spun cables. The amount of elongation consequent on the untwisting is quite insignificant; and, except for these kinks, telegraph cable recovered after three years from 1500 fathoms depth has been found just as good as when it was laid down.

The common iron covered cable can be easily laid safely in depths not exceeding 1000 fathoms; but beyond that depth steel wire should be used for the sheathing, or the specific gravity of the cable diminished. Exposed hemp is not admissible, owing to the marine insects already mentioned, which are found at all depths.

The general result of all the facts that have been ascertained with respect to submarine telegraph cables may be said to be that all the heavy cables have succeeded, and all the light cables failed; and the present tendency is certainly to lay heavier and heavier cables, protected by some composition against rust. It must be remembered however that all the heavy cables except that between Spezzia and Corsica have been laid in shallow water, whereas the small cables have been used in deep water: but the facts by no means prove that some new form of light cable may not ultimately be successful in deep water. The shore end of the new cable about to be laid between Holland and England, shown in Fig. 10, Plate 65, is a fine example of the heavy class of cables, weighing 19·6 tons per nautical mile: the iron wire sheathing is here made double, the core being covered with fifteen wires 0·220 inch diameter, which are served with hemp, and then covered with twelve strands of three 0·220 inch wires each: it is further to be covered with pitch and hemp.

The following Table I (appended) gives the particulars in a tabular form of the actual constructions of cables that have been described and shown in the engravings, together with the weight per nautical mile of each form of cable. Table II gives a list of the principal submarine telegraph cables now in working order; showing the length of each cable, the maximum depth of water in which it is laid, and the length of time it has now been working.

In conclusion the author would remark that he has not attempted to produce a complete account of the various forms of submarine telegraph cables, nor to enter fully into the merits or demerits even of the one most usual type of cable; he has simply endeavoured to draw attention to those points in the different constructions which affect their practical value and durability, so as to bring the subject fairly before the meeting for discussion.

TABLE I.

"Construction and Weight of different Submarine Telegraph Cables.

Date when laid.	Plates 63 to 66.	Locality.	Core.						Iron Sheathing.			Weight per nautical mile of Cable complete.	Remarks.
			Number of separate insulated Conductors.	Number of Wires in each conductor.	Diameter of each Wire.	Diameter of whole Conductor.	Weight of Copper in each conductor per nautical mile.	External diameter of insulating Covering of conductor.	Number of Wires.	Diameter of each Wire.	External diameter of iron Sheathing.		
	Fig.				Inch.	Inch.	Lbs.	Inch.		Inch.	Inch.	Tons.	
1854	4	Spezzia and Corsica ...	6	1	0·065	0·065	70	0·28	12	0·300	1·50	8·50	Deep water; in good working order; has cost nothing for repairs.
1855	5	Varna and Balaclava ...	1	1	0·065	0·065	74	0·30	—	—	—	0·11	No sheathing; lasted nine months.
1857	6	Atlantic, old...	1	7	0·028	0·085	105	0·38	126	0·028	0·62	1·15	Sheathing 18 strands of 7 wires each.
1859	11	Isle of Man	1	1	0·065	0·065	72*	0·34	10	0·190	0·80	2·88	Sheathing covered with asphalte and hemp yarn. *(Weight of conductor approximate.)
1859	7	Red Sea and India ...	1	7	0·038	0·105	180	0·34	18	0·077	0·56	1·05	
1860	8	Toulon and Algiers ...	1	7	0·028	0·085	105	0·34	10	0·085	0·80	1·33	Sheathing, steel wires, each covered separately with tarred hemp.
1861	1	Malta and Alexandria, main cable ...	1	7	0·060	0·165	400	0·46	18	0·120	0·85	2·13	Length 1330 nautical miles successfully laid, chiefly in shallow water; has cost nothing for repairs.
,,	2	Ditto, shore end	1	7	0·060	0·165	400	0·46	12	0·260	1·28	6·90	
1862	9	England and Holland, main cable ...	4	1	0·085	0·085	128	0·34	10	0·375	1·58	10·40	
,,	10	Ditto, shore end	4	1	0·085	0·085	128	0·34	15 36	0·220 0·220	2·00	19·60	Double sheathing; 15 wires covered with 12 strands of 3 wires each.

TABLE II.

Principal Submarine Telegraph Cables now in working order.

Date when laid.	Locality.	Conductors. Number.	Conductors. Diam.	Sheathing. No. of wires.	Sheathing. Diam. of wires.	Length of cable in nautical miles.	Depth of water in fathoms.	Length of time working.
			Inch.		Inch.	Naut. miles.	Fms.	Years.
1851	Dover and Calais	4 wires	0·065	10	0·300	24	—	11
1853	Dover and Ostend... ...	6 ...	0·065	12	0·280	70	—	9
1853	Portpatrick and Donaghadee	6 ...	0 065	12	0·280	22	—	9
1853	England and Holland ...	1 ...	0·065	10*	0·165	105	30	9
1854	Portpatrick and Whitehead	6 ...	0·065	12	0·280	24	—	8
1854	Spezzia and Corsica ...	6 ...	0·065	12	0·300	96	325	8
1856	Newfoundland and Cape Breton ...	1 strand	0·085	12	0·150	74	360	6
1857	Norway, across Fiords...	1 ...	0 085	10	0·200	43	300	5
1857	Ceylon and India	1 ...	0·085	—	0·165	26	—	5
1858	England and Holland ...	4 wires	0·095	10	0·375	122	30	4
1858	England and Hannover	2 strands	0·065	12	0·190	244	30	4
1858	Ceylon and India	1 ...	0·085	12	0·165	26	45	4
1859	England and Denmark...	3 ...	0·065	12	0·210	320	30	3
1859	Sweden and Gotland ...	1 ...	0·085	12	0·150	56	80	3
1859	Folkstone and Boulogne	6 ...	0·085	12	0·340	21	32	3
1859	Malta and Sicily	1 ...	0·085	10	0·210	52	79	3
1859	England and Isle of Man	1 wire	0·065	10	0·190	32	30	3
1859	Tasmania, Bass' Straits	1 strand	0·065	10	0·165	210	—	2½
1860	Toulon and Algiers ...	1 ...	0·085	10†	0·085	452	1585	2
1860	Corfu and Otranto ...	1 ...	0·085	10	0·210	78	1000	2
1860	Dacca and Pegu	1 ...	0·095	18	0·085	100	—	2
1860	Barcelona and Mahon ...	1 ...	0·085	16	0·102	156	1400	2
1860	Majorca and Minorca ...	2 ...	0·065	18	0·110	30	250	2
1860	Iviza and Majorca ...	2 ...	0·065	18	0·115	64	500	2
1860	St. Antonio and Iviza ...	2 ...	0·065	18	0·115	66	450	2
1861	Toulon and Corsica ...	1 ...	0·085	10†	0·085	170	1550	1½
1861	Malta and Alexandria ...	1 ...	0·165	18	0·120	1330	420	½

* Galvanised wires. † Steel wires covered with hemp.

Mr. Jenkin exhibited a number of specimens of the various constructions of submarine telegraph cables described in the paper, contributed by the principal manufacturers, and specimens showing the mode of soldering the successive lengths of the copper conducting wire to one another, and of joining one length of strand to the next by a soldered scarf joint.

Mr. C. W. Siemens thought the subject of the mechanical construction of submarine telegraph cables was one well worthy the attention of the meeting, because it was an open question yet, and one into which mechanical considerations entered very largely. The electrical question, which had also been introduced in the paper that had been read, would perhaps hardly be suitable for discussion on the present occasion; excepting the main point of importance, whether gutta-percha or india-rubber should be used as the insulating covering for protecting the copper conducting wires. He had himself no predilection for either of these materials, but thought both of them possessed very excellent qualities as well as certain defects; it would therefore be wrong to overlook the merits of one in taking too favourable a view of the other. Gutta-percha had been used by himself for a great many years, and he appreciated its advantages and knew also many of its shortcomings, on account of which he had proposed the use of india-rubber as an inner coating under the gutta-percha, not only because of the higher insulating and lower inductive property of india-rubber, but also to a great extent because of its mechanical properties. When once properly put on, india-rubber was so mobile in its particles that it might be called semifluid; and there was no flaw in it so long as it was well protected externally. External protection was necessary in order to make india-rubber effective as an insulator, because if left to itself it would easily be cut; and, what was more important, it absorbed water to a much larger extent than gutta-percha.

The Chairman enquired whether india-rubber absorbed water in consequence of any defect in the material, or whether the absorption was independent of the quality of the india-rubber; and also whether gutta-percha absorbed much water.

Mr. C. W. SIEMENS replied that all india-rubber absorbed water to a very considerable extent, independent of the quality of the material; and gutta-percha also absorbed water, but to a less extent than india-rubber, and never sufficiently to reduce its insulating property materially. From some observations that he had made it appeared that india-rubber was also slightly dissolved by salt water, which gradually formed a slime on the surface of the india-rubber, thereby diminishing its thickness; when immersed in salt water a considerable increase of weight in the india-rubber was first observable for about 150 days, and after that a loss of weight, owing to a slight separation taking place of the slimy substance on the surface of the india-rubber. He had therefore come to the conclusion that the highest insulation could be obtained by a union of india-rubber and gutta-percha: how far either of them used alone could be considered superior to the other must be left for experience to decide; but the experience that he had had of the union of the two was very favourable.

With regard to the outer sheathing of the cable, he considered the subject was treated upon the whole with great fairness in the paper that had been read; many points had been touched upon, some of which admitted of further remarks. Thus in paying out a wire-sheathed cable of the usual construction into deep water, it frequently occurred that one wire broke in the sheathing as the cable was being taken out of the hold, and this was a source of great danger; for the one broken wire with its ends separating from the cable would form an irregular mass, which in passing over the break wheel was very apt to entangle itself there and cause a rupture of the cable. This alone he considered was a sufficient ground for endeavouring to find a sheathing that would not be liable to such accidents; and it was to avoid that liability and to prevent corrosion that he had designed the sheathing now exhibited and described in the paper, consisting of thin copper strips wound round the cable. In this construction the sheathing could not uncoil because it was double throughout along the edges of the strips, and each covering strip was gripped under the succeeding one and was always held down by it, so that even if one of the strips should get cut, or indeed if all of them were

cut at the end of the cable, they could not untwist. With regard to the durability of the external sheathing, he believed there was satisfactory reason for considering that copper, and especially copper with a small percentage of phosphorus (about ¼ per cent.), or of any of the electro-negative metals such as silver or tin, was far more durable in sea water than iron.

The CHAIRMAN observed that he had also found that copper alloyed with a little phosphorus had greater strength and tenacity than when not so alloyed.

Mr. C. W. SIEMENS said experiments had been made which proved also that the copper alloyed with phosphorus was far less oxidisable and therefore far less attacked by the salt of the sea than pure copper. Moreover the copper sheathed cable as it issued from the sheathing machine was covered with a film of tar or resinous matter, which gradually became indurated and formed a strong protection to the metal beneath; and there was also a layer of tar inside the metal sheathing, both of which coatings together with the metal sheathing would have to be oxidised completely through, before the hemp could be laid bare for the marine insects to attack, which was the real danger that would arise if the metal sheathing were gone. For these reasons he thought it was desirable to employ a copper sheathed cable and one that would not uncoil, such as the specimen now exhibited of the new construction, of which some short lengths had now been laid down for trial, and he confidently anticipated the result would be favourable.

He was glad that reference had been made in the paper to the uncoiling of a cable when laid in the sea, which was not admitted by many engineers; it was perfectly true however that when a cable covered with a sheathing wound spirally round it was lowered to a great depth, the strain produced upon it by its own weight, being greatest near the ship and diminishing to nothing at the bottom, would act very much as though the end were freely suspended: the cable would partially untwist and elongate. The consequence of the untwisting was that some sort of loops must be formed at the bottom, where the untwisting action was stopped by the cable lying on the ground; and when the cable was taken up again these loops were

pulled tight into kinks, giving rise to faults in the insulation. If both ends of a cable were held tight fróm untwisting and an equal strain were applied, then indeed the wires would form an arch round the cable, and the elongation produced would only a little exceed the elongation of a solid wire.

The CHAIRMAN enquired what were the principal causes of failure in submarine telegraph cables after they had once been laid, when covered with gutta-percha.

Mr. C. W. SIEMENS replied that there were many causes which had been found in practice to operate in destroying submarine cables made with gutta-percha as the insulating material. In the first place the gutta-percha covering had been imperfect when the cable was shipped for laying. Many cables, especially the earlier ones, had failed because the gutta-percha covering was not perfect, but contained mechanical defects, however good the material itself might be. Air bubbles getting into its substance, in the machine by which the layer of gutta-percha was put on the copper strand, formed cavities which under the great hydraulic pressure at the bottom of the sea would be penetrated by the water. Bad joints in the gutta-percha were another and frequent source of failure. Moreover if too great battery power were applied, the gutta-percha was quite eaten through and melted away in places where the covering happened to be thin owing to a mechanical fault or injury; and it was therefore essential to use low battery power in working cables.

Another frequent cause of failure was the outer sheathing of the cable giving way: the iron wires in some places rusted entirely away, leaving the copper wire simply covered with gutta-percha. Then if the cable had been laid a little tight, or if that part hung between rocks at the bottom of the sea, as soon as the iron covering gave way the weight of the iron sheathing upon the cable would be a great source of destruction, causing those portions where the iron had been rusted away to elongate, and a fault would be developed. This was found to be the case especially in raising a cable after it had been laid some time. In the Red Sea cable, for instance, the iron sheathing had gradually been rusted completely away in some places, and in attempting to raise it the cable broke at those places,

where the gutta-percha was pulled out and faults had developed themselves.

Another cause of failure was the gutta-percha having been melted by accidental exposure to heat. If in a tropical climate a gutta-percha covered cable were allowed to remain lying for a quarter of an hour upon deck, the gutta-percha would unquestionably be softened enough to allow the copper conductor to sink by its weight through the gutta-percha so as to touch the outer materials. Pieces of the Atlantic cable which had been fished up showed evident signs of having been heated. If a piece of iron sheathed cable previously moistened were exposed to atmospheric influence, heat developed itself, as had been the case with the Malta and Alexandria cable; and if that heat rose to about 100° Fahr., the gutta-percha would be in a semifluid condition. When the cable was laid under such circumstances, it might seem successful at first, but faults would show themselves soon afterwards.

Mr. W. Shears remarked that, in reference to the strengthening of copper or brass by a portion of phosphorus being combined with it, he believed phosphoretted metal had no greater durability in sea water than ordinary sheathing as applied to ships' bottoms, either the yellow metal or the copper sheathing, which lasted only a few years: and therefore, notwithstanding the ingenuity of the sheathing of copper strips in Mr. Siemens' cable, he feared it would not stand very long in sea water, probably not more than about three years, and then it would cease to be any protection whatever to the hemp underneath.

Mr. N. S. Russell observed that the durability of copper depended on the quality of the metal, and it was no doubt difficult at the present time to get really good copper that would last well. The copper sheathing of the "Black Eagle" had recently been taken off at Woolwich dockyard, after having been on the ship for twenty years; and it was found to have been only worn thin gradually, but was not worn in holes in any parts, showing how well the sheathing would stand when the metal was of good quality.

Mr. E. A. Cowper said it had been stated before a committee of the House of Commons that copper sheathing as formerly made could be used for twenty-five or thirty years before requiring renewal: but ships

sheathed with modern copper often required stripping in three or four years' time. The plan of mixing phosphorus with copper he believed was a new one; it had only just been tried, so that there had not been an opportunity yet of testing the durability of the phosphoretted copper; but some experiments made with it seemed to give some hope that it would last as well as the good copper sheathing made in former years for ships' bottoms: it seemed to stand well, and did not become oxidised so much as copper not containing phosphorus.

Mr. J. Scott Russell mentioned that some enquiries had lately been made at Chatham into the subject of copper sheathing for ships' bottoms, the practical result of which was that two sorts of copper of the same chemical quality might be of opposite characters for durability in sea water, and to such an extent that while one might be considered as lasting twenty years the other would not last as many months. He had also been informed by a manufacturer of copper that in the process of manufacture the melted copper was skimmed, by taking the "cream" off, and then the "skimmed metal" that remained in the melting pot was employed for the purpose of sheathing ships. But it was found that though this "skimmed metal" was as pure copper as the "cream," and when analysed showed the same chemical composition, yet its quality for the purpose of protecting ships was greatly inferior. It was therefore important in applying copper strips for the sheathing of telegraph cables to learn what sort of copper it was that would last. The durability of the metal was also affected by the degree of friction it was exposed to by motion of the water on its surface; and perhaps the sheathing of telegraph cables, being free from currents in the water, might prove more durable than the sheathing of a ship's bottom. When a ship was laid up in dock, its copper sheathing could scarcely be kept clean; but when in motion it was kept clean by the friction of the water, and the wear of the sheathing consisted in the continual abrasion of its skin by motion through the water. Hence in vessels built with the old fashioned bluff bows, the sheathing had to be put on very thick at the bows, where there was the greatest resistance, to allow for the extra wear at that part in consequence; while in the new fashioned bow, where the resistance was uniform over the entire surface, the copper sheathing wore out more slowly at that part.

Mr. G. A. Everitt could confirm the statement that had been made as to the practice of skimming copper in the process of melting it: the "cream" skimmed off formed what was known as best selected copper, while the "skimmed metal" left behind formed cake copper, which was the description used for copper sheathing, and was the basis of the yellow metal used for sheathing during the last few years. It was therefore readily seen that the present copper sheathing made from cake copper would be much inferior in quality to what it was ten years ago, before the practice of skimming the copper had been adopted for this purpose. As regarded the statement made in the paper in reference to the conducting power of copper wire, that the purer the copper the greater was its power of conducting electricity, he enquired whether any particular makes of copper had been found superior in this respect to others: whether foreign-smelted copper, such as Australian, Russian, or Norwegian, was better than that manufactured in England.

Mr. Jenkin replied that in respect of the power of conducting electricity the Australian copper had been found to be the best.

Mr. E. A. Cowper observed that the copper ores from Cornwall had been found better for the purposes of copper sheathing than either the Australian or the Norwegian; but it was considered to be objectionable to mix many kinds together.

Mr. C. W. Siemens remarked that the power of copper to conduct electricity was very greatly altered by even a slight admixture of any foreign substance: about 2 per cent. of foreign matter was known to reduce the conducting power of copper 87 per cent. He had himself tried the phosphoretted copper, and found that the conducting power was reduced to about one-fifth of what it was before the phosphorus was added. These facts bore very much he considered upon the question of the durability of the copper also, because the action of sea water upon the copper was to a great extent an electric action, and might be greatly influenced by using different kinds of copper on the same vessel; it was well ascertained that one sheet of copper would wear away more rapidly on a ship's bottom than another, and good copper was known to last even from thirty to forty years. The copper however that would be best adapted for sheathing

a telegraph cable was not perhaps that which would be the best for ship sheathing; because in the latter case the copper was not wanted so much to last for any length of time, as to poison the animals that would attach themselves to the ship's bottom, and the yellow metal sheathing had been designed with the special view of poisoning the animals and so keeping them off. If the object were merely to extend the lifetime of the copper sheathing of a ship's bottom, its durability might easily be increased by adding tin, silver, or phosphorus to it; but then it would become more liable to foul by the attachment of marine animals. In the case of a telegraph cable however the conditions were different: durability alone was wanted, and the sheathing was not exposed to any motion in the water. He considered that though the copper sheathing might wear away in some cases in five or six years on a ship's bottom, yet in the sheathing of a cable the same metal would last three or four times as long.

Mr. J. Grantham thought the outer covering of a submarine telegraph cable was practically so much the most important part of the cable that it probably required more consideration than any other point connected with the cable. The new mode of sheathing the cable with copper strips, introduced by Mr. Siemens, appeared to have much to recommend it; for the circumstances affecting the durability of copper sheathing when applied to a ship's bottom and when applied to covering a telegraph cable differed in the important respect that the sheathing of a ship was exposed to the friction of the ship's motion through the water as well as its rolling motion, while the cable lay undisturbed at the bottom of the sea. For the sheathing of a ship it was not in general of so much consequence that the copper should be very durable; because the ship required stripping frequently for caulking the seams, and then the copper was necessarily destroyed and replaced by new; but in a cable the longer the copper sheathing lasted the better. The effect of the friction produced by motion through the water was clearly shown by the greater wear of the copper sheathing at a ship's bows, where the friction was the greatest. The wear indeed was the result partly of chemical and partly of mechanical action: the surface of the copper became oxidised by exposure to the sea water, and if the ship remained at rest the sheathing became covered by a deposit, which

would protect it to a great extent from the effect of the sea water; but by the ship's motion the friction of the water continually brushed off this coating, and thus the animalculæ attaching themselves to the ship's bottom, though probably not poisoned by the copper, could not however cling to it, being thrown off from it by a sort of imperceptible scale, whereby the ship's bottom was preserved free from fouling. These facts were accordingly favourable to sheathing a cable with copper, because the copper would itself become coated in the same manner, and even covered with animalculæ; but while remaining at rest in the water there would be no friction to disturb that coating, which would thus protect the copper from further oxidation by the sea water. There was therefore he thought every reason to suppose the sheathing by copper strips to be a thoroughly sound protection, if the cable were properly manufactured in the first instance: and he enquired whether the strips of copper could be readily obtained of sufficient length to make the manufacture of the cable simple and easy, and so as not to require too many joinings, which would involve some inconvenience.

Mr. C. W. Siemens replied there was no difficulty in manufacturing the copper strips long enough, and they were made in two ways: either long strips were rolled of considerable width, and then cut up into strips of the required width by being passed through a pair of cutting rollers; or else wire was drawn of the required size and length, and was afterwards rolled flat. In both ways strips of sufficient length could be obtained, and there was no difficulty in joining the successive lengths together; they were simply soldered together, and it was not necessary that these soldered joints should be reliable, because each strip was held firmly by the succeeding strip being pressed into it so that it could not get away. In putting on the copper strips on a cable, the sheathing machine was stopped when each strip ran out, while the next length was soldered on.

Mr. A. Smith observed that in reference to the relative strength of steel and iron wire in the construction of telegraph cables, upon which some remarks had been made in the previous discussion upon wire ropes, he had found the statement that steel wire had double the strength of iron wire to be fully confirmed by the results of actual experiments. For an iron wire rope of 1¼ inch circumference, made

of charcoal iron galvanised, broke with a load of $2\frac{1}{2}$ tons, while a steel wire rope of the same size broke with $8\frac{3}{4}$ tons; and an iron wire rope of 3 inches circumference broke at $9\frac{1}{2}$ tons, while a steel wire rope of the same size broke at $26\frac{1}{8}$ tons. Hence he thought a steel wire rope might safely be taken to bear double the strain of an iron wire rope.

Mr. Jenkin said a great number of experiments had been made by Mr. Siemens and Mr. Forde as to the strength of iron and steel wires in submarine telegraph cables, and a great number of single wires had been tried by them. It was found that the steel wire was twice as strong as the iron wire; but on the other hand it was found that, though it had so much more strength when properly manufactured, it could not always be depended upon so well as the best charcoal iron wire: uniformity of strength could not be secured in steel wire, different specimens varying greatly.

Mr. W. Pole said he had lately made some experiments for Messrs. Broadwood upon the strength of pianoforte wire, which was the strongest material known; he had tried several specimens, and was surprised to find the very great strength it possessed. Iron was spoken of as strong when it would bear a tensile strain of 30 tons per square inch, and steel when it bore 60 tons; but the wire he tried actually bore as much as 110 and 120 tons per square inch. It was steel wire, manufactured in Germany; and it had in the form of wire about double the strength of bar steel made of the same material, just as iron wire was generally about twice as strong as bar iron. The iron wire of which the Niagara suspension bridge was made was manufactured in Manchester, and bore a strain of about 40 tons per square inch; and that of the Freiburg suspension bridge in Switzerland, made of charcoal iron, bore 50 tons per square inch.

Mr. J. Scott Russell thought that time was an element which ought to be taken into consideration with respect to the strength of wire; for those metals which bore a very high strain under experiment did not appear to be capable of standing for any great length of time under that strain.

Mr. W. Pole remarked that this was hardly the case with pianoforte wire, because that was found to stand for a long period under a very considerable strain, often not much below its breaking strain.

Mr. P. Haggie observed that in reference to the strength of different sorts of wire the case of pianoforte wire was different from that of a telegraph cable or a wire rope. The pianoforte wire was drawn for a particular purpose, and was made specially hard to stand a great strain; but it was deficient in the flexibility which was specially required in a rope or telegraph cable. The strength of charcoal iron wire however he considered was much more than had been stated, and the wire must have been of very inferior quality in a rope of 3 inches circumference to break with 9½ tons load: for the ordinary test for an iron wire rope of that size was 18 tons, to be borne without breaking. He enquired what was the proportionate strength of the new cable now described, sheathed with copper strips, as compared with cables covered with wire sheathing.

Mr. C. W. Siemens replied that if a wire-sheathed cable were covered with strands of small wire instead of single large wires it could no doubt be made strong enough to be quite safe against any breakage taking place; in fact the former Atlantic cable had been covered in that way, but then the consequence was that it rusted away in about half the time it would have done had single wires been used for the sheathing, on account of the much larger extent of surface exposed to the action of the sea water. For the shore ends indeed of cables a very strong covering of wire strands, something like that now adopted for the England and Holland cable, was certainly the best protection. The copper sheathed cable was not proposed for laying in shallow water, but was intended only for long deep water lines where a heavy cable could not be laid. A cable sufficiently protected with a covering of iron wire would be so heavy that it would be impossible for any one vessel to lay it down across the Atlantic; it would be necessary to stop several times during the paying out to attach another length of cable, and that would be fatal to the whole operation, since the iron would be strained to the utmost safe limit in such a cable to support itself in laying it to a depth of 2000 fathoms. A copper sheathed cable of the size now exhibited, 3-8ths inch diameter, would bear about 1¾ tons load, and therefore as regarded the breaking weight it compared unfavourably with cables covered with iron wire: but taking into consideration its lower specific gravity it was a great

deal stronger than an iron sheathed cable. The copper sheathed cable could be suspended freely in the sea to a depth of six to eight miles before breaking, whereas an iron covered cable would break at three or four miles depth: and this he considered was the proper view to take of the strength of the cable in the case of deep water cables.

Mr. W. Pole enquired whether in the covering of telegraph cables vulcanised india-rubber had proved successful as the insulating material for covering the copper conducting core.

Mr. C. W. Siemens replied that it was only upon brass that vulcanised india-rubber would adhere firmly, and brass had not conducting power enough to be used for the core; hitherto he believed no wire had been produced of copper securely covered with brass. There were also other practical difficulties in the way, which would prevent vulcanised india-rubber from being used as a covering.

Mr. T. Hawksley observed that with regard to the use of phosphorus for alloying the copper for sheathing telegraph cables, with a view to increase the durability of the metal by enabling it to resist the action of the sea water, it was a well known fact that all pure metals had strong chemical affinities, and were always desiring to combine with anything else with which it was possible for them to combine; and accordingly when metals were perfectly pure they were easily destroyed. Thus in cast iron water pipes, and also in the use of malleable iron, if the metal were pure the pipe was speedily destroyed, either by action from within or from without; in water-works this destruction was a source of great annoyance, because it was continually going on, and if the metal were tolerably pure it went on with such rapidity that the water from the pipes could not be kept uncoloured. Those metals however which were not quite pure, but contained a small quantity of sulphur, phosphorus, silica, or carbon, resisted the action of the water, whether from within or from without, much better than the pure metals, and this was the case whether the water were fresh or salt. Hence a metal of the quality of crude steel resisted corrosion far better than pure iron; and cast iron in the vitreous state, or white metal, as it came from the furnace before undergoing the process of puddling, was found to be the best sort of metal for the manufacture of water pipes, provided it was not so hard that it could

not be drilled and worked in the manner necessary for waterworks purposes. There seemed therefore good reason for believing that the durability of the copper sheathing now proposed for telegraph cables would be greatly increased by alloying the copper with phosphorus.

With regard to the transmission of an electric current through a telegraph cable, and the size of conducting wire required, he had made some experiments on the subject several years ago, and then came to the conclusion that the transmission of electricity through a solid conducting rod followed precisely the same law as the transmission of water through a hollow pipe; it required indeed a different coefficient in the case of electricity, but in all other respects the law appeared to be exactly the same. From this law, which he believed had been generally admitted in electricity as Ohm's law, it followed that any long telegraph cable would become useless unless the conducting wire were made of considerable diameter and the intensity of the battery power were kept exceedingly low. Any cables laid with small conducting wires to a distant station such as America must necessarily fail; because if a high intensity of current were employed in endeavouring to obtain great velocity there would be an explosion through the insulating covering, beginning perhaps with only a very minute perforation at first, but ultimately destroying the value of the entire cable. The actual law which he had found by experiment to obtain in regard to the size of the conducting wire was that, in order to maintain an equal velocity of the electric current through varying lengths of cable without increasing its intensity, the diameter of the conducting wire must be increased in the same proportion as the length; but when this was effected the quantity of electricity expended was as the fifth power of the square root of the diameter, being a rather higher proportion than that of the square of the diameter. Unless this proportion were observed he believed that, though it might not be impossible to transmit signals, yet they could not be transmitted with the velocity and safety necessary to make a very long submarine cable commercially successful. He considered the main object to be aimed at in laying long lines of submarine telegraphs ought to be the maintenance of the necessary velocity of the current without any detrimental increase of its intensity.

Mr. Jenkin thought that the failures of submarine telegraph cables had sometimes been considerably magnified by estimating them in an incorrect manner. If the number of miles that had been laid were simply added together, and then the number that had proved successful and unsuccessful, it certainly appeared that about half the total length laid had failed. But it must be remembered that a single fault in a cable 2000 miles long was sufficient to render the whole cable a failure, even though all the rest of it might be in perfect condition; and he therefore considered the most satisfactory way was to take the whole number of miles laid, and the total number of faults that had occurred in them, when the faults would be found to bear but a small proportion to the miles laid. Out of 28 cables that had been laid by one manufacturer since 1854, making a total length of about 3200 nautical miles, all were now at work except only two short cables; and of the rest all but three had gone on without repair from the commencement.

The causes of failure were many, but he believed that in nine cases out of ten the failure was accompanied by a break in the copper conductor. If there were merely a fault in the insulating covering of the cable, without the copper conductor being broken, messages could still be transmitted for a certain time; and he thought the failures that had occurred in the cables across the English Channel and elsewhere had been almost always accompanied by a total breakage of the conducting wire. Some failures had no doubt been caused by small faults and impurities existing in the insulating gutta-percha before the cable was laid; but he did not think that faults in the gutta-percha were ever occasioned by electrolysis, as he believed that gutta-percha in the situation in which it was placed in a telegraph cable was not capable of being decomposed by the passage of an electric current along the cable. He had tried the experiment repeatedly by putting thin films of gutta-percha of the same kind between copper and water, in the condition in which it would be in a telegraph cable, and had been unable to decompose it by any available strength of battery. It would require an exposed point of metal and the passage of an electric spark in order to decompose the gutta-percha, and he had never seen any evidence of holes being burnt in that

way in a telegraph cable. The currents used in signalling did however increase any faults previously existing in the insulating material due to air holes, impurities, or mechanical injury received after the manufacture. At these points a certain fraction of the current passed from the copper conductor to the sea, and in its passage increased the fault both by its chemical action and by the heat developed. A larger and larger fraction of the current was thus diverted, until the fault, small at first, became so considerable that if powerful currents were used heat enough was developed even to melt the gutta-percha: in this way a considerable portion of the copper wire became exposed, and a considerable leak established. It had been the practice then to use more and more powerful currents, which aggravated the injury: and moreover positive currents instead of the ordinary negative currents used to be employed, because by the oxidation which they produced a temporary sealing up of the fault was effected; this however was done at the expense of the copper, which was gradually eaten away. At last by this action the copper was totally severed, and then and not till then all the signals failed entirely. This he believed had been what had taken place in almost all the failures where the cable itself had not been broken.

But although some failures had occurred from imperfections in the core or insulated wire, the cause of failure in the great majority of cases had been the failure of the outside covering; and he entirely concurred in considering that the outside covering was now the most important part of a submarine telegraph cable, because the interior portion could now he believed be satisfactorily manufactured, tested, and preserved. In regard to the durability of copper for the sheathing of a cable, one point that it was important not to overlook was the electrical condition of the copper itself, whether more or less electro-negative, which had a material bearing upon the durability of the metal. This condition appeared to be greatly affected by the temper of the metal, and in the case of ships' sheathing it varied considerably even in different parts of a single sheet of metal, which he thought would account for the unequal wear observed in different portions of the sheathing of a ship's bottom: a few bad places were not of so much consequence in a ship's sheathing, but would be of serious moment in the sheathing of a

telegraph cable, by destroying the strength of the outside covering and allowing the cable to break.

In reference to the difficulty that had been mentioned of paying out a cable safely when covered with iron wire sheathing, owing to the risk of a broken wire sticking out and catching on the paying out wheel, the "brush" as it was called, produced by the running up of the wire on these occasions, certainly looked formidable when seen for the first time; but in several hundred miles of telegraph cable that he had seen paid out he knew of no such instance which had been attended with any fracture or any apparent injury to the cable.

The CHAIRMAN moved a vote of thanks to Mr. Jenkin for his paper, which was passed, and also to the several manufacturers who had kindly lent the large number of specimens of submarine telegraph cables exhibited in connexion with the paper.

The two following papers, communicated through Mr. William Simpson of London, were then read, the discussion on the two being taken together:—

ON THE DOUBLE CYLINDER EXPANSIVE STEAM ENGINE.

By Mr. WILLIAM POLE, of London.

The greatest advances made in the improvement of the steam engine, as an economical means of obtaining motive power, have resulted from the application of the principle of expansion, the advantages of which are now well known and universally appreciated among engineers. This principle has hitherto been applied to the greatest advantage in engines with a single cylinder, used for pumping purposes, as in Cornwall. In these cases the peculiar nature of the motion admits of the steam being cut off after a small fraction of the stroke has been passed over, and allowed to expand during the remainder. When however the principle of expansion is applied in this mode to engines for producing rotary motion, some difficulties arise, which limit considerably the extent that the expansion may be carried to, and therefore reduce in a corresponding degree the economy attained.

The Double Cylinder Engine offers a mode of applying the expansive principle to rotary motion, which removes or at least greatly mitigates the objections to the single cylinder: and it is the object of the present paper to state the nature of the advantages of the double cylinder engine, to explain the principles on which they are based, and to show how these principles have been carried out in practice with satisfactory results.

The original invention of the double cylinder engine is intimately connected with the discovery and first application of the principle of expansion itself; but the unfortunate disputes which for a long time prevailed in reference to this subject have somewhat obscured the history. Having had occasion however some years ago to investigate the matter, the author believes the following account represents the facts as accurately as they can be ascertained.

The double cylinder engine was invented by Jonathan Hornblower, a mechanical engineer of considerable eminence in Cornwall, who took an important part in the application of the steam engine in that district during the early part of Watt's career. The idea appears to have occurred to him early in the year 1776, if not before. He experimented upon a large working model, the cylinders of which were 11 and 14 inches diameter respectively; and he published his invention in 1781, describing it as consisting in the employment of two steam cylinders, the steam after it had acted in the first cylinder being employed a second time in the other, by permitting it to expand itself, the two cylinders being connected together by suitable steam ports and valves. At the same time he described also, shortly but clearly, several other inventions relating to the steam engine: one referring to surface condensing, which is so much applied in modern days; others to means of getting rid of the air and condensed water; and another invention was a steam piston, which, altered into a steam stuffing-box, is in common use at the present time. Here therefore was clearly developed the theoretical principle as well as the practical application of the expansion of steam; and it is beyond dispute that the first publication of the principle to the world was this of Hornblower's. The discovery of this principle however is usually ascribed to Watt, on the strength of a letter written by him to his friend Dr. Small of Birmingham as early as 1769, twelve years before Hornblower published his description; in that letter Watt gives a clear and explicit description of the general principle of expansion. Notwithstanding however the large practice Watt had about this time, it does not appear that he ever applied expansion with any view to economy in its use till 1776, when an engine at the Soho works was altered to work expansively. In 1778 another engine at Shadwell was experimented upon, and Watt published his invention in reference to expansion in 1782, eight months after the publication of Hornblower's. The over-zealous friends of Watt, who, in a spirit so contrary to that of the great man himself, have sought to exalt his fame at the expense of another's, have charged Hornblower with pirating the principle, from surreptitious information of Watt's experiments; but no proof was ever given of the accusation. It is not only highly

improbable in itself, but is altogether negatived by the fact that the originality of the invention on Hornblower's part was expressly admitted by Watt himself. It may therefore be concluded that the discovery of the expansive use of steam, one of the most important and valuable principles in the whole range of practical science, was original both with Watt and Hornblower; and although Watt has established the priority of the idea, the first publication of it to the world was made by Hornblower in the double cylinder engine.

After some years delay, Hornblower proceeded to manufacture his engines in Cornwall; and the miners perceiving that the double cylinder engine acted tolerably well took advantage of it somewhat largely, and in some cases endeavoured to make it supersede Watt's single cylinder expansive engine, which had also then been brought extensively into use. But as it was impossible to make Hornblower's engine work well, without using Watt's separate condenser, invented in 1769, the competition could not be kept up, and the double cylinder engine consequently fell for a time into disuse.

Both Watt and Hornblower had failed to perceive that, to work the principle of expansion to its full advantage, it was necessary that the steam should be admitted to the cylinder in the first instance at considerable pressure. Down to the year 1814, the pressure of the steam in the Cornish engines never much exceeded that of the atmosphere; and so little economy resulted in practice from the application of expansion with this initial pressure that it was found scarcely worth using at all; indeed after Watt's immediate connexion with the district ceased, expansion was rapidly becoming disused and forgotten. The merit of rescuing it from this neglect belongs to two Cornish men, Richard Trevithick and Arthur Woolf; who both about the same time introduced into their native district the true means of advantageous expansion, namely the use of high pressure steam. Trevithick applied this to Watt's single cylinder engine; Woolf applied it to Hornblower's double cylinder engine. The two forms of engine thus for the second time became rivals, and competed well with each other for many years; but it is only with Woolf's modification that the author is now concerned.

Woolf published his invention in 1804, while residing in London. It consisted simply in the application of high pressure steam to Hornblower's double cylinder engine, which he also made double-acting to fit it for rotary motion after the example set by Watt long before. It is obvious therefore that the name "Woolf's engine," by which it is so often designated, is quite erroneous. The engine is entirely and solely Hornblower's invention, and there is no more ground for calling it Woolf's than for calling the present Cornish engine Trevithick's; for Trevithick made the same change with this latter engine that Woolf did with the former, yet no one would on that account think of disconnecting Watt's name from his own engine; and on the same ground Hornblower ought not to be deprived of the credit which the association of his name with his own invention should secure to him. Woolf's ideas respecting the laws of the expansion of high pressure steam were very crude, and it is difficult to conceive how a man of such excellent practical knowledge could have deluded himself into the belief of theories so palpably absurd as those he laid down, upon which he based his statements as to the proposed advantage to be derived from the use of high pressure steam. But although he was so essentially in error on points of theory, he was not wrong in foretelling that much advantage might ultimately be gained by the use he proposed to make of high pressure steam; as was proved beyond a doubt when his engines came to be fairly tried. His strong point was skill in mechanical detail; and his improvements of the engine in this respect were almost innumerable, for there was scarcely a single part which did not receive some beneficial alteration at his hands. Woolf's first engine was erected in 1806 at Meux's brewery in London, to which establishment he was engineer, and subsequently others were fixed in various manufactories; but these did little more than serve him as experiments until 1813, when he returned to reside in Cornwall. Here he found a wide field open for his improvements; he entered in earnest into the manufacture of the engines, and they were highly successful. The new doctrine of high pressure steam produced quite a revolution in the consumption of fuel there; for he at once raised the duty from about 20 millions, at which Watt had left it (that is 20 million lbs. raised one foot high

with the consumption of one bushel or 94 lbs. of coal), to between 50 and 60 millions, thereby saving two thirds of the fuel employed.

But though Woolf was so successful, the Cornish engineers shortly began to see that Trevithick's plan of using high pressure steam expansively in the single cylinder engine promised equally good results with Woolf's, and at the same time got rid of the objectionable complexity of the double cylinder arrangement. Trials on a large scale, in which even Woolf himself was persuaded to assist, soon demonstrated this to be true; the more expensive construction began to be abandoned in the mines, and the Cornish engine gradually settled down into its simplest form; namely, a single engine on Boulton and Watt's construction, but with Trevithick's high pressure steam and high pressure boiler; which form it has retained to the present day. Thus although the double cylinder engine was the first in which the principle of expansion was originally introduced to the world, and about thirty years afterwards was also the first in which this principle was made effective and advantageous, yet in both cases it was ultimately superseded by the more simple form of engine.

It remains now to give some account of the third era of prominence attained by the double cylinder engine, in its revival at the present day. In this revival many modern engineers have aided; but the author considers it the safest course to confine himself to the statement of his own experience, leaving it to others to give an account of what they may have done.

In 1848 the Lambeth Water Works Company, on the advice of their engineer, Mr. James Simpson, took the bold measure of proposing to remove their source of supply to the bank of the Thames at Long Ditton above the tide way; and, as a part of this scheme, it became necessary to force the water by steam pumping power along a cast iron main, nine miles long and 30 inches diameter, from the source to the reservoirs at Brixton Hill. This problem was a difficult one, no experience on so great a length of large main having then been obtained. The great mass of water in motion along the main, combined with the fragile nature of the cast iron, rendered it essential that the motion should go on in the most

equable manner and that concussions or irregularities of pressure should be as much as possible avoided; otherwise frequent fracture of the pipes, fraught with serious consequences to the district they passed through, might be looked upon as almost certain. At the same time, from the large steam power required, it became necessary that all possible improvements in regard to economy of fuel should be adopted. At that time the Cornish single cylinder expansive engine, which had been introduced into London by Mr. Wicksteed, had been somewhat extensively tried for waterworks purposes, and had justified its well known Cornish reputation for economy; but as grave objections appeared to present themselves to its use in this case, on account of the irregularity of the single action, it was determined to ascertain whether the other form of expansive engine, the double cylinder, would not prove more applicable; and since the importance of the case required the most careful consideration, the author was commissioned, in conjunction with Mr. David Thomson, to investigate the subject generally, with a view to the advantageous attainment of the desired economy.

In commencing this investigation it was found that the double cylinder engine had already been to some extent revived, and that modern examples of it, some of considerable size, were working in various parts of the country. These were visited and their action carefully examined; but it did not satisfactorily appear that any engines then met with were sufficiently favourable instances of the application of the expansive principle. The expansion had not been carried to a sufficient extent to produce great economy, nor arranged in the best manner to attain equality of motion; and the arrangement of the valves and passages was generally so defective as to cause great loss of power and waste of fuel. Notwithstanding these unfavourable results however an attentive study of the principles of the engine led to the conclusion that, with a well considered design carefully carried out into practice, the double cylinder arrangement promised not only to be eminently suited to the case in question, but also generally to offer a more beneficial application of the principle of expansion to engines for rotary motion than could be attained with a single cylinder. In accordance with these views, when the Lambeth Water

Works Extension scheme was carried into effect, four large double cylinder engines were designed of 600 total horse power, the working of which has fully justified the expectations entertained of their advantages; their use has been speedily and largely extended to other cases; and the soundness of the principles on which they were constructed may now be said to have been fully proved.

The general theory of the double cylinder engine is so well known that it is unnecessary to repeat it here; the author proposes therefore to confine his remarks to such points as are of interest and importance in elucidating the advantages of this form of engine.

In the first place, in comparing the double with the single cylinder engine it is a mistake to suppose that there is any theoretical advantage on either the one side or the other, in regard to the economical effect of the expansion. It was shown by Watt in an ingenious way at a very early period, and it is demonstrated in the appendix to this paper, that theoretically, if the steam be expanded to the same extent, the economical advantage to be derived from the expansion will be precisely the same, whichever form of engine be adopted for the application. And it further results from the principles of the engine that, for a given initial pressure of steam and a given degree of expansion, the power of the engine, measured by the work it will do in each stroke, depends on the size of the large cylinder only, and is precisely the same as that produced in a single expansive cylinder of the same content. The small cylinder has no effect in adding power, but is merely an appendage, useful only for modifying the arrangement of the expansion and equalising the steam's action during the stroke.

The important objection however against carrying expansion to any great extent in a single cylinder for rotary motion is the great irregularity of pressure at different parts of the stroke. For example, if the steam be expanded in a single cylinder to six times its original volume, by cutting it off when one sixth of the stroke has been passed over, the motive force acting on the piston will be six times as great at the commencement of the stroke as at the end. The accompanying theoretical diagram, Fig. 1, Plate 69, of the varying pressure of the

steam throughout the stroke, when expanded six times in a single cylinder, shows that, assuming the mean total pressure to be 100, the pressure at the commencement will be 215, and at the end only 36; giving an irregularity of 179. The calculation of this and the subsequent theoretical diagrams is explained in the appendix. It is evident that the effect of the great excess of pressure will be to give a heavy blow to the piston at the beginning of every stroke, which must produce violent concussions through the whole of the machinery and tend to produce much mischief and inconvenience in the working. In proportion as a greater degree of expansion is used, the evil will be greater. For example, if ten times expansion be used, the force of the blow at the commencement will be 303, while the mean pressure in the cylinder is still only 100 as before. For this reason in single cylinder engines it has been found difficult to carry the degree of expansion and the consequent economy to the same extent with the rotary as with the single-acting pumping engines. In the latter the piston and all its connexions are free to move under the action of the steam pressure; and therefore the excess of pressure at the commencement of the stroke is at once absorbed in giving velocity to the mass, and does no further harm: but in a rotary engine, the piston being controlled in its motion by the crank and flywheel resists the violent impact, which occurs at the point when it is least able to give way; and the consequence must inevitably be a violent strain, repeated many times every minute, which must ultimately have a prejudicial effect upon the machinery. The advantage of the double cylinder engine is that it mitigates this evil; for when its principles are properly understood and applied, it enables the economical benefit of a high degree of expansion to be obtained with much less irregularity of pressure than in the single cylinder.

In the original double cylinder engines of Hornblower and Woolf the steam was allowed to act first in the small cylinder at full pressure throughout the whole of its length, and then to expand into the larger one, the proportionate cubic content of the two cylinders thus defining the degree of expansion made use of: and it is believed that this method of working was that most commonly used down to the time of the investigations already referred to in 1848. But an enquiry into

the principles of action of the engine shows that it is most advisable not to allow the steam to enter the small cylinder during the whole stroke, but to cut it off after a certain portion of the stroke has been passed over, and to allow the expansion to commence at that point. And it is an important fact, which the author believes not to have been known until published by himself and Mr. Thomson in 1851, that there is a certain point of the stroke, depending on the degree of expansion made use of, at which it is more advantageous to cut off the steam than at any other; for the reason that the irregularity in the motive power, which it is so desirable to mitigate, is then reduced to a minimum.

For example, if the mean motive power of the engine be represented by 100, and the extent of expansion adopted be six times, then in a single cylinder engine the initial blow on the piston at the commencement of the stroke, as previously stated, will be represented by 215, as shown in the diagram, Fig. 1, Plate 69. In a double cylinder engine, if the steam is allowed to enter during the whole of the stroke of the small cylinder, the initial blow will be the same in amount as in the single cylinder engine, namely 215, as shown in Fig. 2; the duration of the blow however is only momentary, as compared with that in Fig. 1, where it continues through one sixth of the stroke. But if the steam is cut off in the small cylinder at 41 per cent. of the stroke, the initial blow is reduced to only 140, as shown in Fig. 3; and this is the minimum blow that can be obtained with the expansion of six times, for on cutting off earlier at 25 per cent. of the stroke the initial blow is increased again to 161. In the diagrams, Plate 69, the comparative motive power is shown in each case throughout the whole stroke of the engine, for the expansion of six times.

It thus appears that, as regards a degree of expansion of six times, if this expansion be effected in a single cylinder, the machinery of the engine will have to bear a sudden blow at the commencement of the stroke, as much as 115 per cent. greater than the mean force due to the effective power of the engine. Next, if a double cylinder engine be employed, and the steam be allowed to enter during the whole stroke of the small cylinder, but little improvement is effected; the blow at the commencement is as great as in the single cylinder, only lasting a

shorter time. But if the same engine be so arranged that the steam is cut off in the small cylinder at the proper point of the stroke, the initial blow may be reduced from 115 per cent. to only 40 per cent. in excess of the mean force; and thus a real and most beneficial improvement may be effected in the action of the engine. This most advantageous point of the stroke for cutting off is determined by calculation in the appendix, and it varies with the extent of expansion adopted in the engine.

The following table shows the best point of cut off under various degrees of expansion, with the corresponding results in the double cylinder and single cylinder engines. The first column gives the number of times the steam is to be expanded; the second shows the percentage of the stroke at which the steam will best be cut off in the small cylinder; the third, the corresponding proportionate area of the small cylinder in percentage of the large one, the length of stroke being the same in both; and the two last columns show the comparative advantage of the double over the single cylinder engine in respect to the excess of the initial blow over the mean motive force. The calculation of these results is explained in detail in the appendix.

Table showing Best Point of Cut Off in double cylinder engine with different degrees of expansion, and Comparative Initial Blow in double and single cylinder engines.

Number of times steam is expanded.	Best Point of Cut off in small cylinder. Percentage of stroke.	Capacity of small cylinder in percentage of large cylinder.	Comparative Initial Blow, the mean motive force being 100.	
			Double Cylinder engine.	Single Cylinder engine.
	Per cent.	Per cent.		
4 times	50	50	126	168
6 times	41	41	140	215
8 times	35	35	151	260
10 times	32	32	161	303

A comparison of the two last columns shows that for a high degree of expansion, such as eight or ten times, the excess of the initial blow over the mean force of 100 is less than one third as great in the double cylinder as in the single cylinder engine. It is clear that the

amount of this initial blow is the maximum strain on the whole of the machinery by which the steam power is transmitted from the piston to the flywheel, and it consequently determines the strength of the various parts necessary to resist this strain. Hence in proportion as the initial blow can be reduced, all these moving parts are required to be less massive in construction; and all are subject to much less violent causes of fracture and derangement in their working.

Another point of improvement to which the attention of the author and Mr. Thomson was prominently directed was the arrangement of the valves and steam passages in the double cylinder engine. In the engines they had the opportunity of examining, the system of valves commonly used was not only complicated, inconvenient, and expensive in construction, but also wasteful in action; the great size and disadvantageous arrangements of the passages caused considerable waste of steam and consequent loss of power and fuel. There is a peculiarity in the double cylinder engine in its requiring a pipe or passage of some kind through which the steam must travel from one end of the small cylinder to the opposite end of the large one; and this passage should evidently be as small in content as possible, consistently with allowing the free passage of the steam. When the communication is opened at the end of the stroke, the steam passing from the small cylinder has to expand and fill this passage before it enters the large cylinder; and if the passage be large, the steam must necessarily suffer a reduction of pressure in so doing, which must seriously diminish its effective action on the large piston during the future stroke, and so cause much loss. In some engines the author found this loss so great as to waste nearly half the power of the engine; and even in the best that were examined such a considerable percentage of loss occurred as almost to neutralise the benefit of expansion altogether.

Much attention was therefore given to this point in designing the new engines; and it was found essential to the success of the engines that some arrangement of valves should be adopted which should satisfy the following conditions:—first, that they should be of the simplest possible character and free from liability to derangement;

second, that they should admit of the steam being cut off from the small cylinder at such a point as might be necessary to secure the required regularity in the motive power of the engine; and third, that they should give the clearance spaces the smallest content possible, and in particular should allow the passage between the two cylinders to be direct and unimpeded and of no larger capacity than absolutely necessary for the passage of the steam. It was further found conducive to economy that the passage between the two cylinders should if possible never be opened either to the high pressure steam or to the condenser, and should moreover be carefully protected from cooling.

A construction of valve was accordingly introduced which combined all these conditions; and was found in its practical working to be very satisfactory. The detailed description of this valve will be given in the succeeding paper by Mr. Thomson.

APPENDIX.

Analytical investigation of the principles of the Double Cylinder Expansive steam engine.

In this investigation it will be convenient to assume that the length of stroke in both the large and small cylinder is the same, and that the pistons move simultaneously with equal velocity, as would be the case if they were both attached to the same point of the beam. In the general investigation also the clearance passages must be omitted; for as their effect depends on the arrangement of the valves, they must be considered specially in each individual instance. Now let

A = area of large cylinder.
a = „ small „
L = length of stroke.
l = length of stroke passed over before the steam is cut off in the small cylinder.

P = total pressure of steam per square inch in the small cylinder before cutting off: this is assumed constant through the space l.

p = back pressure of imperfect vacuum per square inch in the large cylinder.

x = space passed over by the pistons at any point of the stroke, reckoned from the commencement of the stroke.

y = joint effective pressure on the two pistons at the end of the portion x of the stroke.

u_1 = work performed during the portion l of the stroke.

u_2 = " " " remainder "

$U = u_1 + u_2$ = total work performed during the whole stroke.

The whole stroke naturally divides itself into two portions: first *before*, and secondly *after*, the steam is cut off in the small cylinder.

First, *before* the steam is cut off in the small cylinder. Supposing the pistons are making the downstroke, the total forward pressure above the small piston will be uniform and equal to $a\,P$. The back pressure under it will be variable, and will be the same per square inch as the pressure above the large piston, since each end of the small cylinder communicates through the valve with the *opposite* end of the large cylinder. The value of this pressure must be found by considering what has taken place in the preceding upstroke. The steam of pressure P had first filled the small cylinder to a cubic content $a\,l$; and at the end of the upstroke this volume had expanded into a space $a\,L$. Then when the pistons have performed any portion x of their downstroke, the space occupied by the expanding steam will be reduced by the descent of the small piston and increased by the descent of the large one, so that it will become $a\,L + (A - a)\,x$. According therefore to Mariotte's law, which may be taken as sufficiently accurate for the purpose, the pressure per square inch of the steam flowing from the bottom of the small cylinder into the top of the large one, after any portion x of the downstroke has been passed over, will be

$$P \frac{a\,l}{a\,L + (A - a)\,x} \qquad (1)$$

and this, multiplied by a, will be the total back pressure against the small piston at that point of the stroke. The total forward pressure on the top of the large piston will be the same expression (1) multiplied by A; and the total back pressure of the imperfect vacuum underneath the large piston will be $A\,p$.

Hence, adding the effect of the two pistons together to obtain the joint effective pressure y at the end of the portion x of the stroke, before the steam is cut off,

$$y = a\,P + (A - a)\frac{a\,P\,l}{a\,L + (A - a)\,x} - A\,p \qquad (2)$$

The work performed therefore during the portion l of the stroke will be the integral of $y\,dx$ between the limits l and 0, or

$$u_1 = a\,P\,l\left(1 + \log\frac{a\,L + (A - a)\,l}{a\,L}\right) - A\,p\,l \qquad (3)$$

Secondly, *after* the steam is cut off in the small cylinder. Here the forward pressure in the small cylinder is variable; for after a length of stroke x the volume of steam which was originally $a\,l$ will be increased to $a\,x$, and the pressure per square inch will consequently be diminished to $P\,\frac{l}{x}$; so that the total forward pressure on the small piston will be $a\,P\,\frac{l}{x}$. The back pressure on the small piston and the forward pressure on the large one will be found by the same expression (1) as before; so that the joint effective pressure y on the two pistons, after the steam is cut off, will be

$$y = a\,P\,\frac{l}{x} + (A - a)\frac{a\,P\,l}{a\,L + (A - a)\,x} - A\,p \qquad (4)$$

And the work performed during this latter portion of the stroke will be the integral of $y\,dx$ between the limits L and l, or

$$u_2 = a\,P\,l\log\frac{A\,L^2}{a\,L\,l + (A - a)\,l^2} - A\,p\,(L - l) \qquad (5)$$

Adding therefore equations (3) and (5) together, the total work developed during one entire single stroke of the two pistons will be

$$U = u_1 + u_2 = a\,P\,l\left(1 + \log\frac{A\,L}{a\,l}\right) - A\,p\,L \qquad (6)$$

It may now readily be seen that the theoretical effect of the expansion is the same with the double as with the single cylinder engine. For in this last equation $\frac{A\,L}{a\,l}$ represents the final extent of the expansion, or the number of times the steam is increased in volume from the time it is cut off in the small cylinder to the end of its action in the large one. If this be represented by E, so that $E\,a\,l = A\,L$, then if the dimensions of the large cylinder be used, the work done in a single stroke will be

$$U = \frac{A\,L\,P}{E}(1 + \log E) - A\,L\,p \qquad (7)$$

which is precisely the same expression as represents the work of steam used expansively in a single cylinder whose area is A and length of stroke L, and in which the steam is cut off at $\frac{1}{E}$th part of the stroke. The work performed by a given quantity of steam is therefore exactly the same in the double cylinder engine as in the single cylinder engine, with the same extent of expansion in both cases, as was stated in the paper.

The last equation (7) also furnishes the proof of the further principle stated in the paper, namely that, for a given initial pressure of steam and a given degree of expansion, the power of the engine, measured by the work it will do in each stroke, depends solely on the size $A\,L$ of the large cylinder.

The volume of steam at the initial pressure P used to perform the work U is $\frac{A\,L}{E}$; from which the *duty* of the engine may be found in the usual way.

If the length of stroke be taken in feet, the areas of the pistons in square inches, and the pressure in lbs. per square inch, according to the usual practice, and if N be the number of single strokes per minute, then the theoretical *horse power* of the double cylinder engine will be

$$\text{Horse power} = \frac{A\,L\,N}{33000}\left\{\frac{P}{E}(1 + \log E) - p\right\} \qquad (8)$$

It must be remembered that P is the pressure of steam in the small cylinder during the period before cutting off, and not the pressure in the boiler which is generally much higher.

It can now be shown that, for an engine of given power and given expansion, there is a point, as stated in the paper, at which the steam may be cut off in the small cylinder, so that the excess of power at the commencement of the stroke may be a minimum. Simplifying equation (2) by omitting the imperfect vacuum, and making $x = 0$, the joint effective pressure y on the two pistons at the commencement of the stroke is

$$y = P\left\{a + (A - a)\frac{l}{L}\right\}$$

Let $\frac{l}{L}$, the fraction of the stroke at which the steam is to be cut off, be represented by z, the independent variable. Then since E

representing the extent of the expansion, as before, is to be constant, and since the power of the engine, which is measured by the size of the large cylinder, is also to be constant, the area of the small cylinder a will be variable and equal to $\frac{A}{E\,z}$; whence the total initial pressure y is

$$y = A\,P\left(\frac{1}{E\,z} + z - \frac{1}{E}\right) \qquad (9)$$

which must be a minimum. Treating this in the usual way by differentiating and putting $dy = 0$, the simple result arrived at is that the initial force or blow is a minimum when

$$z = \frac{1}{\sqrt{E}} \qquad (10)$$

that is when the area of the small cylinder is so proportioned to that of the large one as that the fraction of the stroke at which the steam is cut off shall be equal to the reciprocal of the square root of the given degree of expansion.

Substituting this value in equation (9), the *initial blow* at the commencement of the stroke in the double cylinder engine will be

$$y = A\,P\left(\frac{2\,\sqrt{E} - 1}{E}\right) \qquad (11)$$

whereas in a single cylinder engine of the same power and expansion the initial blow will be

$$y = A\,P \qquad (12)$$

which is greater than that given by the preceding equation, since E is necessarily greater than 1; and a comparison of these two equations in any individual case will show the exact advantage of the double cylinder over the single cylinder engine.

The *mean* motive power in either engine will be found by dividing the total work U in equation (7) by the length of stroke L, neglecting the imperfect vacuum; which will give

$$\text{Mean motive power} = \frac{A\,P}{E}\,(1 + \log E) \qquad (13)$$

The last two columns of the table given in the paper are calculated from the two previous equations (11) and (12), taken in connexion with the last equation (13). The third column, giving the proportionate size of the small cylinder as compared with the large one, is obtained from the equation

$$\frac{a}{A} = \frac{1}{E\,z} = \frac{1}{\sqrt{E}} \qquad (14)$$

and the second column, calculated from equation (10), is identical with the third, since these equations (10) and (14) are the same. The ordinates or vertical dimensions in the theoretical diagrams Figs. 2 and 3, Plate 69, for the double cylinder engine, are calculated from equations (2) and (4), omitting the imperfect vacuum; and in Fig. 1, for the single cylinder engine, they are simply taken inversely as the portion of the stroke passed over from the commencement.

ON DOUBLE CYLINDER PUMPING ENGINES.

By Mr. DAVID THOMSON, of London.

The Double Cylinder Pumping Engines referred to in the previous paper by Mr. Pole as having been erected by Messrs. Simpson at the Lambeth Water Works, Thames Ditton, were designed and executed under the superintendence of the author of the present paper, in which it is intended to give a general description of the engines, with a few practical remarks suggested by the experience of their performance.

The general arrangement of these engines is shown in Fig. 1, Plate 70. They are beam engines, having the double cylinders A B at one end of the beam, and a crank C and connecting rod at the other end; four engines of 150 horse power each are fixed side by side, arranged in two pairs, each pair working on to one shaft, with cranks at right angles, and a flywheel D between them. The strokes of the crank C and of the large cylinder A are equal; while the small cylinder B, which receives the steam direct from the boiler, has a shorter stroke, and its effective capacity is nearly one fourth that of the large cylinder. The pumps E are connected direct to the beams near the connecting rod end by means of two side rods, between which the crank C works. The pumps are of the combined plunger and bucket construction, and are thus double-acting although having only two valves: the author believes that this kind of pump, which is now in general use, was first introduced by him at the Richmond and Bristol Water Works in the year 1848. The following are the principal dimensions of the engines:—

Diameter of large cylinder	46 ins.
„ small cylinder	28 ins.
Stroke of large cylinder	8 ft. 0 ins.
„ small cylinder	5 ft. $6\frac{3}{8}$ ins.
Diameter of pump barrel	$23\frac{3}{4}$ ins.
„ pump plunger	$16\frac{1}{8}$ ins.
Stroke of pump	6 ft. $11\frac{5}{8}$ ins.
Length of beam between extreme centres	26 ft. 6 ins.
Height of beam centre from floor	21 ft. 4 ins.

The principal peculiarity of these engines is in the valves and valve gear: the valves are so constructed that one valve effects the distribution of the steam in each pair of cylinders. Fig. 2, Plate 71, is a vertical section through the centres of the two cylinders and valve, which are drawn as if situated in the same straight line, for convenience of illustration; but the correct position of the valve in connexion with the two cylinders is shown in the sectional plans, Figs. 3 and 4, Plate 72, taken through the steam ports of the large and small cylinders respectively. The valve F, of which the top end is shown enlarged in Fig. 7, Plate 73, consists of four small pistons GG, 14 inches diameter, connected together by a pipe H which forms the passage whereby the steam is conveyed from one end of the small cylinder to the opposite end of the large cylinder. The action of the valve is shown by the two diagrams, Figs. 5 and 6, Plate 73, which represent its two extreme positions at the commencement of the up and down strokes. The steam from the boiler enters the annular space I surrounding the middle of the valve; and the communication with the condenser J, Fig. 1, is at KK, beyond the top and bottom ends of the valve. With the valve in its lowest position, as shown in Figs. 2 and 5, Plates 71 and 73, the steam from the boiler is admitted into the bottom of the small cylinder B, for making the up stroke; and the steam from the top of the small cylinder is exhausted through the hollow pipe H of the valve into the bottom of the large cylinder A, while the top of the large cylinder exhausts direct into the condenser, beyond the top end of the valve. Figs. 6 and 7, Plate 73, show the valve in its highest position, for admitting the steam in the corresponding manner at the beginning of the down stroke.

The cylinder ports are rectangular, with inclined bars across the faces to prevent the packing rings of the valve from catching against the edges of the ports: and the bars are made inclined instead of vertical in order to avoid any tendency to grooving the valve packing. The openings of the port extend two thirds round the circumference of the valve in the ports of the large cylinder, as shown in Fig. 3, Plate 72; but they extend only half round in the ports of the small cylinder, as shown in Fig. 4. The packing of the valve consists of the four cast iron rings GG, Fig. 7, Plate 73, which are cut at one

side exactly as in an ordinary piston, the joint being covered by a plate inside. A considerably stronger pressure of the rings against the valve chest is required than was at first expected, because the openings of the steam ports extend so far round the valve; and for this purpose springs are placed inside the packing rings to assist their own elasticity. This construction of valve has the advantage of admitting of great simplicity in the castings of the cylinders; and also allows of the whole of the valve work being executed in the lathe, which is generally both the cheapest and most correct kind of work in an engineering workshop. These valves are worked by cams, which are not well adapted for engines working at high speed; and this led the author in the construction of some recent double cylinder engines to adopt valves and valve gear of a different construction; but he has not been able to design any which surpass or even equal these in the economical distribution of the steam.

The principal object aimed at in the construction of this piston valve was the reduction to a minimum of the loss of pressure which the steam undergoes in passing from the small cylinder to the large one. This is here accomplished by making the passage of moderate dimensions and as direct as possible; and also by preventing any communication of this passage with the condenser, so that when the steam from the small cylinder enters the passage, the latter is already filled with steam of the density that existed in the large cylinder at the termination of the previous stroke. In constructing the engines some doubt was entertained as to the best size of passage, in order on the one hand to avoid throttling the steam, and on the other to obviate as much as possible the loss of steam in filling the passage. The size adopted was a pipe 6 inches in diameter, or 1–60th of the area of the large cylinder, for a speed of piston of 230 feet per minute in the large cylinder; and this is believed to be about the best proportion, the entire cubic content of the whole passage in the valve amounting to 3944 cubic inches. The indicator diagrams, Figs. 8 to 11, Plates 74 and 75, show that with this construction of valve there is very little or no throttling of the steam; and also that there is but a very moderate drop in the pressure as the steam passes from the small cylinder into the large one. In this respect the valve completely

answered the expectations entertained of it, and left little farther to be desired on this point.

The accompanying indicator diagrams, Figs. 8 to 11, Plates 74 and 75, taken from the Lambeth Water Works engines, show the action of the steam throughout the stroke.

In Fig. 8, Plate 74, the upper diagram is that taken from the bottom of the small cylinder, and the lower is the corresponding diagram from the top of the large cylinder. Fig. 10, Plate 75, is the diagram taken at the same time from the top of the small cylinder, to which however there is none corresponding from the bottom of the large cylinder; but as the diagrams from the two ends of the small cylinder so nearly correspond, it may be presumed that a diagram taken from the bottom of the large cylinder at the same time would have been very nearly the same as that from the top, shown by the lower diagram in Fig. 8.

In Fig. 9, Plate 74, the upper diagram is that taken from the top of the small cylinder, and the lower is the corresponding diagram from the bottom of the large cylinder; while Fig. 11, Plate 75, is the diagram taken at the same time from the top of the large cylinder, to which however there is no corresponding diagram from the bottom of the small cylinder. The dotted lines in Figs. 8, 9, and 10, represent the exhaust line in the small cylinder reversed, so as to show by direct measurement of the distance between this and the top line of the diagram what is the effective or working pressure on the small piston at any part of the stroke.

In order that these diagrams may be compared with theory, it is necessary to know the cubic contents of the cylinders with the given lengths of stroke, of the clearances at the ends of the cylinders, and of the different parts of the steam passages. The following are the capacities of these spaces :—

	Cub. Ins.	Cub. Ins.
Capacity of small cylinder, 5 ft. $6\frac{3}{8}$ ins. stroke		40870
Clearance at end of small cylinder	308	
Space in port between valve and small cylinder	805	
Total space between valve and small piston .		1113
Capacity of large cylinder, 8 ft. stroke		159542
Clearance at end of large cylinder	831	
Space in port between valve and large cylinder	2844	
Total space between valve and large piston .		3675
Capacity of all passages in valve		3944
Sum of last two capacities		7619

Hence the steam escaping from the small cylinder has to expand into an additional space of 7619 cubic inches before it reaches the large piston.

The following table shows the principal results deduced from these indicator diagrams, in the calculation of which it has been assumed that the space occupied by the steam when expanded is inversely as the pressure; and also that the valve and pistons were steam-tight when the diagrams were taken, which is believed to have been nearly the case. For the sake of simplicity also the steam enclosed in the valve passage has been neglected, and the passage is supposed to be empty when the steam from the small cylinder enters it. The effect of the clearances and steam passages has been taken into account in calculating the expansions.

These indicator diagrams show in different degrees a few results which the author has constantly observed in all the indicator diagrams he has taken from double cylinder engines. In the first place, the pressure of the steam at the end of the stroke, instead of falling short of what it ought to be by the theoretical expansion curve, always exceeds that amount. In Fig. 8, Plate 74, this excess is as much as 30 per cent., and in Fig. 9 it is 23 per cent. of the actual final pressure. This fact has been often observed before to a smaller extent in single cylinder engines, and has been said to be peculiar to cylinders without jackets or external means of keeping up their heat. But in this case both cylinders were jacketted, and the jackets were supplied with steam of a higher pressure than the maximum pressure in the cylinders. It might be supposed that the increased pressure at the end of the stroke

Table of Results

Deduced from the Indicator Diagrams, Figs. 8 *and* 9, *Plate* 74.

	Fig. 8.	Fig. 9.
1. Percentage of stroke at which steam is cut off in small cylinder	25 per cent.	40 per cent.
2. Total expansion at end of stroke in small cylinder, in terms of bulk before expansion . . .	3·78	2·41
3. Amount of expansion on passing from small to large cylinder, in terms of bulk before escaping from small cylinder	1·18	1·18
4. Total expansion at end of stroke in large cylinder, in terms of original bulk	15·15	9·66
5. Total amount of efficient expansion, in terms of original bulk	12·80	8·19
6. Total pressure of steam per square inch at point of cutting off	32 lbs.	41 lbs.
7. Theoretical total pressure at end of stroke of small piston	8·4 lbs.	17·0 lbs.
8. Actual total pressure shown by diagram . .	10·6 lbs.	18·0 lbs.
9. Excess of actual over theoretical in percentage of actual pressure	21 per cent.	6 per cent.
10. Theoretical loss of pressure in passage from small to large cylinder	1·7 lbs.	2·6 lbs.
11. Actual loss shown by diagram	2·5 lbs.	4·5 lbs.
12. Theoretical total pressure at end of stroke of large piston	2·1 lbs.	4·2 lbs.
13. Actual total pressure shown by diagram . .	3·0 lbs.	5·5 lbs.
14. Excess of actual over theoretical in percentage of actual pressure	30 per cent.	23 per cent.
15. Mean pressure on crank pin from both cylinders	15240 lbs.	22400 lbs.
16. Maximum ditto	27838 lbs.	36058 lbs.
17. Ratio of maximum to mean	1·83 to 1·00	1·61 to 1·00
18. Ratio of maximum to mean pressure on crank pin in a single cylinder engine with the same total amount of efficient expansion (art. 5), the clearances and ports bearing the same proportion to working capacity of cylinder, namely 1–40th part; this ratio is calculated from the ordinary logarithmic expansion curve	4·00 to 1·00	2·75 to 1·00
19. Efficiency of steam contained in large cylinder at end of stroke, as shown by diagram, if used without expansion, taken as	1·00	1·00
20. Actual efficiency of same steam as employed in both cylinders, as shown by diagram . .	2·70	2·90
21. Theoretical efficiency of same steam if expanded to same degree as total amount of efficient expansion (art. 5)	3·56	3·10

was due to the heat imparted from the jackets either superheating the steam or converting the watery vapour mixed with it into true steam; and probably the latter is the cause of a small part of the observed effect: but in the author's opinion it is not likely that sufficient heat could be communicated from the jackets to produce an increase of 23 per cent. in the actual final pressure, much less of 30 per cent. This is the more unlikely because on several occasions the condensed water from the jackets has been collected and found not to exceed half a gallon per hour. The experiments made on the quantities of water passed from the boilers give uniformly the result, that a considerably larger quantity of water passes from the boilers than is accounted for by the indicator diagram, taking the quantity and pressure of the steam just before it escapes to the condenser as the basis of calculation. In some trials made within a few days of the indicator diagram Fig. 8, Plate 74, being taken, the excess of water thus disappearing from the boilers was about 37 per cent. It appears however to the author that this constant excess of the actual over the theoretical final pressure of the expanded steam is still not satisfactorily explained. To suppose that the valve was leaking might account for it; but besides great care having been taken to avoid this source of error, it can hardly be supposed that the valve was always leaking more than the pistons.

Secondly, although the pressure of the steam in the cylinders in these engines always exceeds what would be given by theory, yet the loss of pressure in passing from the small cylinder to the large one always exceeds what would be expected from theory. This fact holds as universally as the previous, in the author's experience, although by no means to a uniform extent.

Thirdly, the table shows the great practical advantage that the double cylinder engine possesses in moderating the extreme strains on the machinery which are produced when expansion is carried to a great extent in a single cylinder: the maximum pressure on the crank pin from both cylinders is here only 83 per cent. greater than the mean in the diagram Fig. 8, and only 61 per cent. greater in the diagram Fig. 9. It is indeed impossible in practice to carry expansion in one cylinder to so high a degree as is shown in these diagrams. Although

single cylinder engines are frequently said to be expanding ten times, the author has not known any instance of their being so worked continuously, but only occasionally and experimentally; and in no case that he is acquainted with has the expansion ever been more than nominally to the extent of ten times, that is the steam has been cut off at 1–10th of the stroke from the commencement. In such a case the size of the valve passages and clearance of the piston amount to so large a proportion of the steam in the working part of the cylinder at the moment of cutting off that a nominal expansion of ten times is often in reality not more than six or seven times. In the small cylinder of the double cylinder engines now described the passages and clearances are reduced to a minimum, and are much smaller than in most single cylinders of the same size; and yet if the steam were here cut off at 1–10th of the stroke these passages would amount to one fourth of the volume of the steam contained in the cylinder at the moment of cutting off, and the expansion in this cylinder instead of being ten times would be only about eight times. This is a point too generally neglected in estimating the merits of different engines or discussing the results of indicator diagrams.

To ascertain the amount of friction in these engines the author has made many experiments, and has found that, when the engines are new and working at perhaps little more than half their power, the loss in comparing the work done with the indicator diagrams amounts to as much as 25 per cent. of the indicated power; but in these cases the pistons have been too tight in the cylinders, and when this error has been corrected and the engines worked up to their regular work all the losses are brought down to from 12 to 15 per cent. of the indicated power. This includes the friction of both the engines and the pumps, the working of the air pumps, feed pumps, cold water pumps, and pumps for charging the air vessels with air.

On the whole the author is of opinion that where expansion is carried to an extent of only three or four times, the single cylinder form of engine is simpler and better than the double cylinder; but where expansion is required to a much higher degree, the double cylinder presents the only way of carrying it out successfully in practice. When the double cylinder is adopted an ordinary expansion

of not less than ten times should be effected, if it is desired to get a result corresponding with the additional complication incurred. The theory of the action of steam jackets appears still somewhat doubtful, but there can be no doubt that with high expansion in two cylinders they are absolutely essential to a favourable economical result.

With regard to the economy of fuel attained by the double cylinder engines, it may be stated that the four pumping engines at the Lambeth Water Works are fixed in one house and are employed in pumping through a main pipe 30 inches diameter and about nine miles in length; and when all the engines are working together at their ordinary speed of 14 revolutions per minute, the lift on the pumps as measured by a mercurial gauge is equal to a head of about 210 feet of water. Under these circumstances they were tested by Mr. Field soon after being finished, in a trial of 24 hours' duration without stopping. The actual work done by the pumps during this trial was equal to 97,064,894 lbs. raised one foot high for every 112 lbs. of coal consumed; in addition to which this consumption included the friction of the engines and pumps, and the power required to work the air pumps, feed and charging pumps, and the pumps raising the water for condensation. The coal used was Welsh, of good average quality.

The economy in consumption of fuel during this trial and in the subsequent regular working of these engines, together with the satisfactory performance generally of the engines and pump work, induced the Chelsea Water Works Company and also the New River Company each to erect in 1854 a set of four similar engines, which were made almost exactly the same as the Lambeth Water Works engines already described, with the exception that a jacket of high pressure steam was in these subsequent engines provided under the bottoms of the cylinders, which had not been done with the previous engines. The pumps were also different in size to suit the different lifts.

The New River engines were tested soon after being completed, and the result reported was 113 million lbs. raised one foot high by 112 lbs. of Welsh coal. But this duty was obtained from a trial of only 7 or 8 hours' duration, which is too short to obtain very

M 2

trustworthy results; and similar circumstances the author believes have given rise to the extraordinary statements that have sometimes been made regarding the duty obtained from steam engines.

The set of engines made for the Chelsea Water Works was the last finished, and on completion the engines were tested by Mr. Field in the same manner as the Lambeth engines, by a trial of 24 hours' continuous pumping. The coal used was Welsh, as before, and the duty reported was 103·9 million lbs. raised one foot high by 112 lbs. of coal. This, as in the previous instance, was the duty got from the pumps in actual work done, no allowance being made for the friction of the engines and pumps, and the power required to work the air pumps, cold water pumps, &c. At the time of these engines being tested the loss by friction and by working the air pumps, &c., averaged about 20 per cent. of the power as given by the indicator diagrams; so that if the duty had been estimated from the indicator diagrams, as is usual in marine engines, it would have been $103 \cdot 9 \times \frac{100}{80}$ or about 130 million lbs. raised one foot by 112 lbs. of coal, which is equivalent to a consumption of 1·7 lbs. per indicated horse power per hour.

Mr. Pole said that in the investigation of the double cylinder engine he had been desirous of entering rather fully into its history, which had previously been involved in some obscurity. Few seemed to be aware of the extent of Hornblower's connexion with the engine, which was generally called Woolf's, although it was certainly Hornblower's invention; and the principle of expansion, one of the most important principles in the steam engine, was first introduced to the world in Hornblower's engine. The revival of this same engine at a subsequent period was due to Woolf, who simply applied high pressure steam to it, as was done also about the same time by Trevithick to the single cylinder engine in Cornwall; in the latter case the circumstances were so far different from those of other engines that the single cylinder engine was here undoubtedly the best for the purpose to which it was applied.

The double cylinder engine, as now practically carried out in the manner described in the paper last read, proved a very useful arrangement, by affording the means of carrying the important principle of expansion to a much greater extent than was practically possible in the single cylinder engine. In a single cylinder engine, when applied to pumping without a crank and flywheel, it was indeed possible to make use of a considerable degree of expansion, because the blow which then inevitably came at the commencement of the stroke was immediately absorbed by the inertia of the mass: but when the piston was controlled by a crank and flywheel he thought experience proved that it was scarcely possible to expand more than four or five times without producing a very great strain on the machinery; beyond that expansion the engine could not be made strong enough, and the blow was what no engineer would like to incur. This was made clear in the three theoretical diagrams exhibited, (Plate 69,) which were all constructed for the same total amount of expansion of the steam, namely six times. The first diagram showed that in the single cylinder engine the initial blow was 2·15 times the mean pressure throughout the stroke, and the force of the blow continued undiminished during one sixth of the stroke, after which the pressure dropped according to the regular expansion curve. The second diagram gave the combined effect of the two cylinders in the double cylinder engine, when the steam was kept on at full pressure throughout the entire stroke in the small cylinder: this was the original plan in the use of two cylinders, and the plan generally followed; but the diagram showed that the initial blow was here still the same as in the single cylinder engine, namely 2·15 times the mean pressure, the steam then passing at full pressure into the large cylinder at the moment of commencing the stroke; and although the pressure immediately fell off rapidly, instead of continuing during any length of the stroke, yet the machinery had necessarily to be made as strong as before, in order to stand the same initial blow, so that no practical advantage was gained. His object however had been to show in the paper that the initial blow might be greatly reduced and its injurious effect avoided by first expanding the steam partially through a portion of the stroke in the small cylinder, and then

completing the expansion in the large cylinder; and also to show that by the adoption of this plan a point of cut off could be found at which the initial blow would be reduced to the minimum. The third diagram gave the result of cutting off the steam at the most advantageous point in the small cylinder, namely 41 per cent. of the stroke, whereby the initial blow was reduced to the minimum, being then only 1·40 times the mean pressure throughout the stroke, instead of 2·15 times as previously, and the line was much more equable throughout the stroke, approaching much more nearly to the mean pressure; but an earlier cut off would have the effect of again raising the force of the initial blow. These theoretical results were fully borne out by the practical results obtained in the double cylinder pumping engines that had been described, in which the principle of expansion was now carried to a greater extent than would be possible in a single cylinder engine with crank and flywheel, and without being attended with the disadvantages that a single cylinder would entail.

The Chairman enquired what experience there had been as to the durability of the long cylindrical slide valve between the two cylinders in the double cylinder engine.

Mr. Thomson replied that in the case of the Chelsea and the Lambeth Water Works engines the valves had proved quite as durable as the ordinary pistons made with metal packing rings were found to be. But in the engines at the New River Water Works the valves had not been so durable, nor had the pistons, and much inconvenience was suffered from this circumstance; the reason had been found to be some peculiarity in the tallow used for lubrication, which caused the substance not only of the valves but also of the pistons to become eaten away. Now however, in place of the tallow previously used, animal fat procured in an unmanufactured state had been employed for the last twelve months, which had produced a great improvement in the durability of the valves and pistons, and the metal was now not nearly so much acted upon as it was before.

The Chairman asked what was the initial pressure of steam at the commencement of the stroke, and also the pressure in the boilers: and whether the actual final expansion of the steam was really as much as fifteen times.

Mr. Thomson replied that in the engines from which the indicator diagrams were taken the boiler pressure was 40 lbs. per square inch above the atmosphere, and the initial pressure of the steam in the small cylinder was 35 lbs. The expansion in the first indicator diagram appeared to be 16 times, if merely the point of cut off were taken into consideration; but by including the effect of the capacity of the ports the actual expansion was 15 times, and if the useless effect of the expansion of the steam into the valve between the cylinders were also deducted, the total efficient expansion was found to be 13 times nearly; that is the volume occupied in the cylinders alone by the steam at the end of the stroke was 13 times as great as at the point of cut off. The steam would therefore be in reality expanded to that extent if its expansion followed the regular logarithmic curve; but the indicator diagram showed that the final pressure at the end of the stroke was 30 per cent. in excess of the theoretical pressure corresponding to the total expansion of 15 times, and therefore the actual expansion was proportionately less.

Mr. J. Grantham enquired whether the steam was superheated in the engine from which the indicator diagrams had been taken.

Mr. Thomson said the steam was not superheated, except by the heat obtained from the steam jacket of the cylinders which was filled with steam at the boiler pressure.

Mr. J. Grantham thought that would probably account both for the pressure of steam being raised at the end of the stroke above the theoretical pressure, and also for the loss of water from the boiler, which had been stated to amount to 37 per cent. in excess of the consumption of water as calculated from the volume of steam contained in the small cylinder at the point of cut off. This extra amount of water must evidently have been carried off from the boiler mixed with the steam by priming, and then became evaporated at the end of the stroke by the heat from the steam jacket: but if the steam had been superheated immediately on leaving the boiler, before entering the cylinder, no water would have passed over with it, and there would have been no loss of water from the boiler, while the pressure would have followed the regular curve during the expansion.

The progress of the application of expansion in the steam engine, of which so interesting an account had been given, was a remarkable history, and seemed to have been divided into three distinct eras, the original idea of expansion having virtually died out after its first promulgation, until revived in 1814 by Trevithick and Woolf in connexion with a higher pressure of steam; then it again fell into neglect, and the great majority of engines were worked with little or no expansion whatever; and it was only within the last few years that the subject had now been again revived. The principle of expansion was one of such great practical importance that it required the most attentive consideration in all classes of steam engines. He remembered seeing at Stroud about twenty years ago a small double cylinder engine of about four horse power, which had been put up about thirty years previously by Woolf himself; it was employed in a brewery, and had a large cast iron boiler with some cast iron tubes through it, and the boiler was apparently as good as ever after thirty years' work, during which it had been going on without repairs. The engine was working with high pressure steam, about 60 lbs. per square inch above the atmosphere, and showed a remarkable economy in fuel, quite unequalled by any of the numerous other engines employed in the woollen manufacture in that neighbourhood: the latter however, though good engines, were all worked on the common low pressure system, and in none of them was the use of high pressure steam with expansion ever adopted for about twenty years after the erection of Woolf's small engine. A second engine on the same plan was however at length put up there, of about 30 horse power, carrying out the principle of expansion with high pressure steam; and this engine had at the time he saw it been working for nearly ten years consuming only about $2\frac{3}{4}$ lbs. of coal per horse power per hour, whereas many engines in the neighbourhood were using as much as 12 lbs.: yet no one else had at that time attempted to repeat the engine, notwithstanding the extent of steam power employed in the neighbourhood. This was an illustration of the indifference with which so important a subject had been treated, and not in that district alone, but throughout the entire country; but now that it was again revived, the question could not be discussed too frequently,

not only as regarded manufacturing purposes, but more especially in reference to marine engines.

From an examination of the various steam engines exhibited in the present International Exhibition he was confirmed in the opinion that the expansive use of steam was much more fully carried out on the continent than in this country, probably arising from the greater cost of fuel there. On the continent the double cylinder engine was in common use and had been so for many years, and in some localities he believed it was used exclusively. It was moreover curious that in most of the descriptions given of these engines Woolf's name was associated with them; and foreigners generally seemed to look upon Woolf as the originator of the double cylinder engine, which strictly he was not, although he revived its use, and thereby probably did a greater service than even the original inventor, because he brought into use what Hornblower had not succeeded in establishing.

Since the time of Woolf's revival of the double cylinder engine, so great an advance had been made in the construction of stronger boilers and the use of a higher pressure, and in the introduction of superheating, that there was now a better prospect of extending the adoption of this engine, in which expansion could certainly be carried to a much greater extent than in a single cylinder, as shown in the paper. But there was still much to be done in respect of increasing the pressure of steam in stationary and marine engines, in which at present the common practice was to use only about 25 lbs. pressure per square inch, whereas in locomotives the pressure was frequently as high as 150 lbs., and would probably be carried higher. If this pressure could be attained in marine and stationary engines, great economy of fuel would result; but the greater expense required in the construction of the engine in the first instance was in most cases the obstacle in the way of any high degree of expansion; and even where an engine was provided with separate valves for working expansively, the expansion valves had been abandoned, and the full steam kept on through the entire stroke, involving a wasteful consumption of fuel. The papers that had been read would he thought do much towards advancing the general knowledge of the value and practicability of the double cylinder arrangement.

In pumping engines indeed, such as had been described, the slow and deliberate action, and the careful way in which such engines were generally attended to, afforded peculiar advantages for carrying out the application of the double cylinder engine; but there were other cases, especially marine engines, in which economy of fuel was evidently of far greater importance than in pumping engines, because the weight of fuel formed a limit to the load that could be carried: and to marine engines therefore the application of a high degree of expansion was particularly desirable. It was not necessary however to adhere closely to the arrangement of the double cylinders that was adopted for the pumping engines, which in many cases would be inconvenient, since it would necessitate either four cranks for two pair of cylinders, or else the use of a beam for each pair as in the pumping engines. In the marine engines shown in the Exhibition by Mr. Humphrys, similar to those working in the "Mooltan" with Hall's surface condensers, the small cylinder was mounted on the top of the large one and the same piston rod was carried through both cylinders, requiring some alteration in the arrangement of the passages to convey the steam from the small cylinder to the large one: but the short distance that the steam had here to travel from the bottom of the small cylinder to the top of the large one compensated for the long distance it had to travel from the top of the small to the bottom of the large cylinder, so that he believed there was altogether not much difference in loss of pressure in the steam passages between these engines and the double cylinder pumping engines shown in the present paper. There was also a small horizontal engine among the Belgian machinery in the Exhibition, designed for driving the gunboats of the Swedish navy, which had a small cylinder placed within a large one, with three piston rods, one from the inner piston and the two others from the outer annular piston; the high pressure steam was admitted to the inner cylinder, whence it was conveyed to the outer low pressure cylinder by passages through the cylinder covers, with a considerable loss of pressure in the passages in this case on account of their length. In other respects the arrangement seemed good, and it was simple and well adapted for the purpose for which it was intended.

Mr. J. Scott Russell said the introduction of a high degree of expansion in marine engines was greatly to be desired, but the difficulty attending it was the great strain thrown upon the machinery at the commencement of the stroke compared with the mean force of the entire stroke; and it was with the view of obviating this difficulty that he had himself designed some years ago the plan which had been mentioned of putting the small cylinder inside the large one and working with three piston rods, admitting the high pressure steam to the inner cylinder and expanding into the outer. There were however several inconveniences for the practical purposes of steam navigation in any of the combinations of cylinders that he had yet seen. Working with two cylinders was attended with certain trammels in the case of marine engines, which virtually limited the expansion to a particular grade; whereas the special want in steam navigation was the means of working with a great variety of grades of expansion, and sometimes with no expansion at all, but with the full power of both cylinders. When this difficulty was surmounted, the great practical inconvenience of double cylinder engines for marine purposes would be got rid of. Another difficulty in the way of extending the degree of expansion was the want of a better class of men to attend to the engines placed in vessels; until superior men were employed it would be unwise to attempt obtaining the large economy that would result from greater expansion, higher pressure, superheating, and surface condensation, with the use of more costly engines and stronger boilers. In order to get over the difficulty of repairs, arising from the complexity of a double cylinder engine, he had arranged an engine with three separate cylinders, all working expansively and acting direct upon one crank, so as to have the free use of any degree of expansion without the disadvantage of the double cylinder arrangement. With this engine, expanding the steam about four times in each of the three cylinders, the consumption of coal in ordinary working was brought down to about 2½ lbs. and even 2 lbs. per horse power per hour. Marine engines however had not the same advantages for great expansion as pumping engines, in which the large mass to be put in motion absorbed the excess of power at the beginning of the stroke, and served as a reservoir of power to perform the remainder of the work when the high pressure of the steam was reduced by expansion.

Mr. E. E. Allen observed that the alleged difficulty of obtaining a temporary increase of power had been frequently urged against the use of double cylinder expansive engines for marine purposes, but he was not able to see how the objection applied, because the steam, instead of being cut off at a third or a half of the stroke or at any other point that was desired, might be kept on for the full length of stroke in the first cylinder, when the full power of the engine was wanted. In ordinary marine engines cutting off at three quarters of the stroke there was no means of adding to the power more than about one fifth; but if a larger and more expansive engine were used, with the steam cut off at one third of the stroke in the small cylinder, which was what was generally proposed in double cylinder expansive marine engines, the power could be increased between two and three times. An important difference moreover between the application of the double cylinder expansive arrangement to marine engines and to other purposes was that, while it was quite possible in pumping engines and in most other cases to lengthen the cylinders for an increased expansion, making the length of stroke frequently three or four times the diameter, it was impossible to do so in marine engines, which were confined within very narrow limits, so that the cylinders assumed a different shape from those in other engines; in marine engines of 1200 horse power now being made the diameter of the cylinder was more than double the length of stroke, the diameter being nearly 10 feet while the stroke was only 4 feet. In cylinders of these large diameters however, not only was the initial blow of the steam very much in excess of anything that was met with in pumping engines, but there was a heavy loss in the clearance space at the end of the cylinder, bearing a large proportion to the whole steam used if the steam were cut off at an early part of the stroke. The double cylinder engine had therefore a great advantage for short strokes, by reducing the initial blow with a high degree of expansion, and he believed it afforded the only practical mode of carrying out expansion to any high degree in marine engines. He had proposed placing the cylinders horizontal, with the small cylinder at the back of the large one, instead of the vertical arrangement adopted in the "Mooltan" and other vessels, because he objected to raising the engines, especially when the cylinders were large and heavy.

The degree of expansion and point of cut off to be adopted depended upon the pressure of steam employed: with an initial pressure of 20 lbs. per square inch above the atmosphere he had proposed that the steam should be expanded 7 times, and about 10 times for 60 lbs. total pressure, and perhaps 18 times for 120 lbs., the economy obtained being greater the higher the pressure of steam used. The expansion of 7 times was the same that had been adopted by Mr. Humphrys and Messrs. Randolph and Elder with 20 lbs. steam or 35 lbs. total pressure, the object being to expand the steam down to a final pressure of about 4½ or 5 lbs. per square inch above a vacuum.

When expansion was fully carried out in marine engines there was reason to look forwards to the consumption of fuel being reduced to less than half what it now was. At present the average consumption reached 4½ or 5 lbs. per indicated horse power per hour, but by expanding 7 times with 20 lbs. steam he believed this would be brought down to 2¾ lbs. per horse power per hour; and if surface condensation were employed in addition, the consumption would be further reduced to 2¼ lbs. of fuel, which was the actual consumption in the engines of the "Mooltan" during a continuous sea voyage, and also in Messrs. Randolph and Elder's engines.

Mr. E. A. Cowper did not consider it was necessary to adopt the plan that had been mentioned of having three cylinders in marine engines for obtaining a high degree of expansion; nor did he think the other plan of putting the small cylinder inside the large one was altogether advisable, as it involved certain complications of construction. In the latter case, although there were two cylinders, they could act only on one crank; and the outer annular piston would be subject to a great amount of wear, by being confined between the two cylinders, instead of being left as free as possible in working, which was particularly desirable in a marine engine. The use of two cylinders of different size with cranks at right angles had been tried several times, by Mr. Zander about fourteen years ago, by Mr. Rontgen about eleven years ago on the Rhine, and by himself twelve years ago, the steam expanding out of the small cylinder into the large one: this plan required a space between the two cylinders for the steam to expand into on leaving the small cylinder, because at the end of the

stroke of the small cylinder the crank of the large cylinder was at half stroke, and therefore not in the position for taking steam, so that a steam-jacketted reservoir was required into which the steam could be exhausted from the small cylinder, and in which it could be kept without any loss of heat and be slightly superheated before being admitted into the larger cylinder. In this particular arrangement he had found that a great advantage in uniformity of power was obtained by cutting off the steam at particular points near half stroke in both cylinders: it had been proposed many years ago to cut off the steam at half stroke, with the view of obtaining uniformity of rotative power; but the exact point of cut off had to be ascertained for each case, to produce the best result. The total variation from the average rotative power when the steam was admitted through the whole stroke in both cylinders was 31 per cent.; but when cutting off at the most advantageous point near half stroke in each cylinder it was only 14 per cent. This was shown in the diagram, Fig. 12, Plate 75, in which the curve L represented the rotative power obtained from one cylinder throughout one revolution of the crank, as measured by the height of the curve at successive points from the base line X, which represented the path of the crank; and the curve M represented the power obtained at the same time from the second cylinder, the steam being admitted throughout the whole stroke in each cylinder. The curve N gave the combined rotative power of the two cylinders at the successive points of the entire revolution, measured from the base line Y; and showed an extreme variation in the power of 31 per cent. from the average line P. The curves R and S showed similarly the rotative power when the steam was cut off at the most advantageous point near half stroke in both cylinders; and the curve T gave the combined rotative power of the two cylinders in that case, showing a variation of only 14 per cent. from the average line U, and thus giving a practical uniformity of effect. In the diagram the length of the connecting rod had been taken into account. In the case of using full steam throughout the whole stroke it had also to be observed that the variations in rotative power were not only large in amount but long continued; for instance in the first quarter of the revolution the power was greatly in excess of the average, but in the third quarter it was

greatly below the average, as shown by the curve N in the diagram. When cutting off however at the most advantageous point, each quarter of the revolution had nearly the same rotative power, as shown by the curve T. The amount of power not obtained from the steam, owing to the drop in the expansion curve at the point of exhausting into the reservoir from the small cylinder, when cutting off at nearly half stroke in both cylinders and expanding nearly nine times, was very small in amount, and formed an insignificant portion of the whole power, as shown by the combined indicator figures taken from the two cylinders, compared with the true expansion curve or such as would be given from a single cylinder having the whole expansion performed in it. This was the result that had been obtained with a 40 horse power horizontal engine constructed on this plan by Messrs. Walter May and Co., shown at the International Exhibition. The great uniformity of rotative power obtained, together with the great economy, would prove most important advantages in the case of cotton mills, flour mills, marine and pumping engines, and indeed manufactures generally.

Mr. T. Hawksley remarked that from his own experience he believed that in pumping water the single cylinder rotative engine expanding the steam not more than three or four times, with a boiler pressure not exceeding 30 lbs. per square inch above the atmosphere, was for all ordinary purposes the best kind of engine that could be adopted. Such an engine did not indeed realise all the advantages which theory assigned to the double cylinder engine, and the power of the steam might undoubtedly be utilised to a greater extent by carrying the expansion further. But practically, whether as regarded the first cost of the engine or its durability or the facility of its management, he was convinced that a single cylinder engine, worked as he had mentioned, was as a general rule the best that could be applied to pumping purposes. Where the district to be supplied was generally flat, such as the east of London, and where the water could be delivered into a stand-pipe to one uniform height, he considered the single cylinder Cornish engine with loaded plunger was eligible for pumping. Also in raising water from a deep pit, which frequently had to be done for the supply of towns as well as in draining mines,

he had found the Cornish engine was again practically the best, because it worked under a uniform steady pressure without being exposed to fluctuations from any cause, and gave due time for the rods to come to rest; and this was a case in which the expansion could be carried somewhat further than three or four times. There were cases however in which it was desirable to use the double cylinder engine, and these formed probably the great majority of all the cases that occurred in waterworks: where the water had to be pumped either direct into the town or into a remote reservoir, and where consequently the water was taken off from the mains at intermediate and irregular intervals, producing a considerable variation in the amount of pressure; and also where the height to which the water had to be raised rendered a stand-pipe unavailable. Here it was found useful to apply a flywheel; and it was then also desirable to carry out the expansion to a considerable extent, as the steam could in practice be expanded further when a flywheel was used than in the Cornish engine without flywheel. It therefore became a consideration how best to get this increased amount of expansion; and the double cylinder engine was found, as shown in the first of the two papers that had just been read, to afford the means of so limiting the initial blow of the steam as that practically there was no necessity for employing a great weight of material to obtain the requisite strength in the engine, since the strain on all the machinery could be reduced to a minimum for a given power, by properly adjusting the proportions of the two cylinders and cutting off at the proper point of the stroke in the small cylinder.

In reference to the actual extent of expansion that could be realised, very high degrees of expansion were often spoken of, with corresponding economy of fuel; but he considered the expansive power of steam at ordinary pressures could not be realised beneficially beyond a limited extent, because the passive resistance in an engine of moderate size amounted practically to something like 5 lbs. per square inch on the piston. The back pressure from defective vacuum in the cylinder was rarely less than 2 lbs. per square inch in the best constructed engines: and the working friction of the engine under its load, even in engines of considerable size, was seldom below 3 lbs. per square inch on

the piston; sometimes it was rather less, but only in large engines. Hence there was no gain in carrying the expansion so far that the pressure of the steam should at any time be reduced to less than 5 lbs. per square inch above a perfect vacuum, since every portion of the stroke that was done with a pressure below 5 lbs. per square inch was done at a loss. Pumping engines for waterworks were generally worked with steam at about 30 lbs. per square inch above the atmosphere or 45 lbs. total pressure, and consequently the steam ought not to be expanded more than nine times under those circumstances. If therefore under such circumstances steam were expanded as much as fifteen times from the same initial pressure in the engines described in the paper, as had been stated, part of the expansion must have been performed at a loss.

It had also been stated that in one trial of the double cylinder pumping engines a duty was realised of about 130 millions of lbs. raised one foot high by 112 lbs. of coal, giving a consumption of about 1·7 lbs. per horse power per hour; but by the ordinary calculation that would require an expansion of forty times, and as it was clear this could not have been the case, he could only conclude there had been some mistake in the experiment, which might readily arise from a variety of causes. It might not be theoretically impracticable to get down the consumption of coal to 1·7 lbs. per horse power per hour, but he was convinced it was altogether impossible to do so under the practical circumstances in which steam engines were placed, either in pumping or on board ship or in driving machinery. He was acquainted with the double cylinder pumping engines described in the paper, which were certainly working with extraordinary economy, and he believed the discrepancy in the account of their consumption was sufficiently explained by the further statement that 37 per cent. of water had been lost out of the boilers beyond the consumption that corresponded with the volume and pressure of steam contained in the small cylinder at the point of cutting off. That extra quantity of water was no doubt carried over into the cylinder partly in the form of water mixed with the steam, and partly as steam leaking in through the valves after the cut off: for if the steam were not superheated on leaving the boiler, it was only by passing it through a large chamber

where it could deposit the water mixed with it before entering the cylinder that the actual expansion curve in the indicator diagram could be brought into conformity with the theoretical line; but when this provision was made, and when the valves were perfectly steam-tight, he had found the actual curve coincided as nearly as possible with the theoretical. He therefore believed the loss of water that had been stated fully explained the higher pressure which was shown in the indicator diagrams at the end of the stroke, above the final pressure that would have resulted from regular expansion.

In the use of high pressure steam its effect upon the materials of the engine was a subject that required some consideration. He had had an opportunity of watching the progressive change from low pressure to high pressure steam that had taken place during the last thirty years, and in one instance that had been under his observation a low pressure pumping engine erected and set to work in 1831 had still at the present time all its working parts and even the boilers nearly as perfect as at the time when it was put up; while on the other hand engines using high pressure steam of 30 lbs. and under, subsequently erected at the same place, had had the cast iron parts and many of the wrought iron parts completely cut through in the course of ten years. This could not be due as had been supposed to the quality of the tallow, for the same quality of tallow had been used in both cases; but he believed it was entirely due to a cutting or destructive action of the high pressure steam itself. This was therefore one of the causes of expense which would limit the use of high pressure steam in all cases where durability of the machinery was an important point.

In making a trial of any engines in order to ascertain the consumption of fuel, the condition of the boiler at the time ought not to be left out of the consideration. For if the boiler were thoroughly cleaned and the flues also cleared of soot, the evaporation might be increased in an experiment to the extent of 25 or 30 per cent. beyond what was obtained in the ordinary working condition of the boiler; and hence such experimental results could not be relied upon as any sure guide for what might be expected in regular practice. It was therefore important that in all statements of the quantity of water evaporated by a given consumption of fuel the condition of the boiler should be stated as well.

Mr. Pole remarked that, in reference to the extent of expansion that could be adopted with a given pressure of steam, there was no doubt a point beyond which no further advantage could be got from expansion, because the size of cylinder would have to be increased so much that the passive resistance of the engine would become so great as to overbalance the benefit of the expansion. But he thought this certainly could not be the case in expanding up to eight or nine times with steam of 30 lbs. per square inch above the atmosphere; and he believed that for practical purposes it was not intended to work the double cylinder engines to a greater extent of expansion with that pressure.

As regarded economy of fuel and the alleged impossibility of getting the consumption so low as 2 lbs. of coal per horse power per hour in regular practice, the reports of the Cornish engines showed that many of the best engines had been working regularly for years together with a duty of 90 millions of lbs. raised one foot high by one bushel or 94 lbs. of coal, which was equivalent to a consumption of 2 lbs. of coal per horse power per hour. The duty which had been stated to have been obtained in the trial of the double cylinder engines, 113 millions with 112 lbs. of coal, was also equivalent to the same consumption of 2 lbs. of coal per horse power per hour; and although this might seem an exceptional duty for the double cylinder engines, he believed it would not be found so, but that in regular working they would fall very little short of the best Cornish engines.

Mr. T. Hawksley observed that the engines used in Cornwall, from which so high a duty had been obtained, were an exceptional class of engines; and even in these the duty at the present time had come down from the former amount of 90 millions to a duty now of only 56 millions on an average per bushel of coal. At the time when the engines were worked at the high duty of 90 millions, it was a common saying that a lb. of tallow was equal to a bushel of coal, and the engines all competing with one another got more than their proper allowance of tallow, so that the consumption of coal was diminished by the excessive lubrication. He was therefore satisfied that in engines of ordinary size and under ordinary circumstances it was a mistake to imagine that any such high results as had been spoken of could be

practically and economically realised in regular working, or even results within 50 per cent. of them.

Mr. Pole said it was certainly the case that the engines in Cornwall had receded from their former high duty, because when an engine was put up new it cost less in working than afterwards; and moreover as the workings in the mine were extended deeper, the engine had more work to do and the steam could not be expanded so much, so that less economy was then obtained.

Mr. J. Scott Russell concurred in the importance of not carrying the expansion so far as that the pressure of the steam should ever be reduced below the passive resistance of the engine, in the case of marine engines and rotary engines generally where no flywheel was used; but in pumping engines with a heavy beam or flywheel he thought the limitation was not so applicable, because here the reservoir of momentum in the heavy mass in motion could be drawn upon for carrying the engine on to the end of the stroke even after the pressure of steam in the cylinder had been reduced below the resistance of the engine, when without the aid of that momentum the steam alone would be of no avail.

Mr. Thomson said that, in reference to the annular construction of double cylinder engine that had been mentioned, he had last year made two pumping engines on that construction of 60 horse power each, and also a small double cylinder engine for a yacht which made from 300 to 330 revolutions per minute. In the latter instance the arrangement was modified by making the two pistons travel in opposite directions, in order that the engine might be balanced; and with the same object the centre piston was made heavier than in other engines, so as to be the same weight as the annular piston. The point of cut off in the small cylinder could also be varied from one quarter to three quarters of the stroke, and the expansion consequently altered between those limits. This engine had moreover a surface condenser, with a cold water pump to draw off the condensing water from it, worked at the same speed as the engine; but though the speed was so high there was no shake at all in the pipes of the pump.

With regard to the practical advantage of expanding the steam more than three or four times, and the amount of the passive

resistance of the engine, the indicator diagrams exhibited, as well as others that had frequently been taken from the double cylinder pumping engines shown in the drawings, gave a defective vacuum of only about 1 lb. per square inch; while the total dead resistance of the engine, including this defective vacuum, certainly did not amount to anything like 5 lbs. per square inch on the piston. He had also tried some experiments recently with several different degrees of expansion in one of the two 60 horse power pumping engines with annular cylinders that he had mentioned, in order to ascertain the degree to which the expansion could be advantageously carried in practice. For this purpose the evaporative duty of the boilers was entirely left out of the account, and the engine having injection condensers the quantity of injection water supplied was measured by a meter and thereby kept uniform: the load on the engine was also kept almost perfectly uniform, as the engine was employed in pumping water, and a counter was attached to ascertain that there was no variation in the speed of working; the work done by the engine was thus measured and maintained as uniform as possible. The expansion was then varied to different degrees whilst working, the initial pressure of the steam admitted to the cylinder being increased as the degree of expansion was increased, so as to keep the total power of the engine uniform throughout the experiment, to correspond with the uniform work to be done. The steam was first cut off at 7-10ths of the stroke in the small cylinder, giving an efficient expansion of 5·7 times, neglecting the expansion in the passages and clearances, since the larger or annular cylinder was four times the size of the small inner cylinder: and the temperature of the waste water in the hot well being measured was found to be 96° Fahr. The expansion was then increased by cutting off the steam 1-10th earlier in the stroke successively, and the following results were obtained:—

Point of Cut off in small cylinder.	Total Efficient Expansion.	Temperature of Water in hot well.
7–10ths of stroke	5·7 times	96 degrees Fahr.
6–10ths "	6·7 "	94½ "
5–10ths "	8·0 "	93½ "
4–10ths "	10·0 "	92 "
3–10ths "	13·3 "	91½ "
2–10ths "	20·0 "	91½ "

Hence it appeared that no improvement was effected by cutting off earlier than 3-10ths of the stroke, making the efficient expansion 13·3 times; for on increasing the expansion to 20 times with the cut off at 2-10ths of the stroke, the temperature of the waste water in the hot well was no further reduced, but remained the same as in cutting off at 3-10ths. In the temperatures obtained in these experiments the diminution indeed was certainly not so great as it ought to be by theory; for with a temperature of 96° when the steam was cut off at 7-10ths of the stroke, the diminution of temperature on cutting off at 3-10ths ought to have been something like $1\frac{1}{3}$ or $1\frac{3}{4}$ times what was actually found.

The Chairman suggested that the quantity of water lost from the boiler by priming and carried over with the steam into the engine would probably account for the higher temperature in the hot well, as well as for the increased pressure of steam at the end of the stroke. He enquired what was the initial pressure of the steam when it was expanded thirteen times.

Mr. Thomson thought that all the heat which passed off from the engine must find its way into the condenser, and would there be shown by the temperature of the water in the hot well, which was therefore taken as the measure of the waste of heat accompanying each grade of expansion. No heat would pass into the condenser beyond that which remained in the steam at the end of the stroke after expansion, excepting of course a certain quantity of heat imparted from the steam jacket of the cylinder, which would be the same under all circumstances. The initial pressure of the steam at the time of expanding thirteen times was about 30 or 35 lbs. per square inch above the atmosphere, as shown by the indicator diagram: in ordinary working however the steam was cut off at half stroke in the small cylinder, which gave an expansion of eight times, the large cylinder being four times the size of the small one; or seven times efficient expansion, neglecting the passages and clearances.

Mr. T. Hawksley considered the experiments that had been mentioned with different degrees of expansion did not furnish any proof that the higher expansions were not carried on at a loss; and he thought this would not be detected by the plan which had been

adopted of measuring the temperature in the hot well. For in an extreme case of a cylinder of excessive length, if the steam were cut off so early as to be expanded below the passive resistance of the engine long before the end of the stroke were reached, the latter part of the stroke would all be done at a loss, without the steam exerting any appreciable force on the piston; but still almost the same quantity of heat would be sent forwards into the hot well as if the stroke had been stopped at that point where the pressure of the expanded steam was just balanced by the passive resistance of the engine. It was therefore important to make sure in every case that none of the previously gained power should be afterwards wasted in merely overcoming the useless resistance.

Mr. E. E. Allen observed that with steam of 35 lbs. per square inch total pressure an expansion of seven times would reduce the pressure to 5 lbs. per square inch above a perfect vacuum, and he was not aware that it was ever proposed to expand further with that pressure of steam, certainly not in marine engines; since it was generally considered useless to reduce the final pressure below that amount, which usually covered the friction of the engine and the back pressure of the condenser; and therefore a higher expansion could be adopted only when a higher initial pressure of steam was used. It was accordingly impossible to fix any particular grade of expansion for all cases, but the expansion must always be proportional to the initial pressure of steam, so that with 55 lbs. total pressure the steam should be expanded ten or eleven times.

With regard to the consumption of fuel, he fully concurred in the opinion that, if the steam were only 35 lbs. per square inch total pressure, by no possible arrangement could the consumption be reduced to less than about 2 lbs. of coal per indicated horse power per hour, which was the limit even when surface condensation was adopted. But if greater economy were desired, the pressure of the steam must be raised; and then with 120 lbs. steam there would not be the slightest difficulty he believed, even in a marine engine, in reducing the consumption to about 1¼ lbs. of coal per indicated horse power per hour.

In reference to the particular form of engine best adapted for marine engines, the only objection that he knew of to the three cylinder arrangement, or the double cylinder with cranks at right angles, was the multiplication of connecting rods and piston rods; whereas by putting the small cylinder at the back of the large one, upon the same piston rod, only one connecting rod was required, and all the parts were reduced to the smallest size compatible with the initial pressure of the steam on the small piston and the pressure of the expanded steam on the large piston. If it were attempted to expand much in a marine engine with only a single cylinder of large size, such as 10 feet diameter, all the parts would have to be made strong enough to bear the full pressure of the steam on that large area at the beginning of the stroke; while for all the rest of the stroke the strength of the parts was much above what was needed. In the double cylinder arrangement however the high pressure steam admitted into the small cylinder was reduced by expansion to about a third of its initial pressure, before being let into the large cylinder, whereby the weight of the engine was reduced fully 2½ cwts. per nominal horse power.

As regarded the back pressure of the imperfect vacuum, many experiments had been made on this point, and he believed that good marine engines would work regularly with a back pressure of about 2½ lbs. per square inch; the friction of the engine also amounted to about 1½ or 2 lbs. per square inch on the piston, as had been stated; and the total passive resistance of the engine was therefore about 4½ lbs. per square inch, below which pressure the steam certainly could not be usefully expanded, whatever its initial pressure might be.

The Chairman proposed a vote of thanks to Mr. Pole and Mr. Thomson for their papers, which was passed.

The following paper, communicated through Mr. J. Scott Russell of London, was then read :—

ON THE CONSTRUCTION AND APPLICATION OF IRON ARMOUR FOR SHIPS OF WAR.

By Mr. NORMAN S. RUSSELL, of London.

The problem of forming an iron fleet would at first sight seem a simple matter; for starting with the following facts, proved by experiment—first, that 1 inch thickness of iron breaks up shells so as to prevent their explosion as shells; secondly, that 2½ inches thickness of iron stops them completely, and prevents the fragments of the broken shell from being carried through the ship's side like grape; and thirdly, that 4½ inches thickness stops the heaviest shot fired from the most powerful guns which the science and manufacturing skill of this country have hitherto produced—it is only necessary that the vessels of the present wooden fleet, as they already exist with engines on board, should be coated with the heaviest of these three thicknesses of iron which each ship is able to carry, and an iron-plated fleet will then be obtained. It is true that this immense fleet will cost more than a new and effective one of equal power; that not one of these vessels would be able to cross the Atlantic; that the entire fleet could not prevent a single fast cruiser from seizing all the gold ships on their way from Australia; and that they would not effectively blockade the coast of any foreign power with whom there might be war: our supremacy at sea would be gone, but we should be safe from invasion, and able to stop an enemy attempting to land here.

This problem has already been tested with regard to the iron-coated French and English batteries. Several of them were built by this country and sent on their way to the Crimea; but after several disasters, and going as fast as they could under steam and sail, they got only half way, and returned to this country having done nothing: in short they were not sea boats. Such an iron-plated wooden fleet

would be of a little more value than local batteries on shore, but only a very little; they could shift their position it is true, and provided it was known where an enemy intended to land, they could prevent his landing; but their advantage in this respect over land batteries would hardly compensate for their superior cost.

If it is desired to retain our supremacy at sea, a fleet must be formed that can not only fight a battle, but also ensure winning it. Such a fleet must be designed and constructed anew from the beginning; whether it shall be constructed entirely of iron or with wood backing to support the armour plates is still an open question; but in order to possess all the good qualities which are required in naval warfare, there can be no doubt that the structure of the vessels must be of iron. The real difficulty of the problem consists in this, that any existing ship of war when iron-coated will be slow, unseaworthy, and combustible, and will be incapable of long voyages; whereas the fleet of England must be able to keep at sea for a long time, to steam long distances, to go faster than the ships of any other country, and to be in better condition than other fighting vessels in all weather, especially the worst. The whole difficulty consists in designing vessels possessing all these qualities in addition to being shot-proof.

To begin the consideration of an iron shot-proof fleet, by taking an example of a vessel which it would be wished to construct if possible; the question arises, can shot-proof gun boats such as have hitherto been built be now built 140 feet long, 24 feet beam, of 80 horse power, and carrying 4 guns; and the answer is, they cannot be built, because the weight of iron would sink them. Even an iron-plated corvette of a favourite class, 190 feet long, 36 feet beam, and drawing 16 feet of water, propelled by 250 horse power engines, could not be constructed. In short, to carry a high side out of the water, the ship cannot be much less than 60 feet beam; and to go with the requisite speed it must have a length of about 400 feet; it would then be a completely shot-proof iron ship worthy of the British fleet, but even this vessel would be 7000 tons burden. Smaller vessels can of course be built, but if they are to have good qualities and are intended to act in concert with the more powerful vessels, they must be only partially coated and will be compromises.

The first ship of this class will be like the "Warrior," shown in Fig. 1, Plate 76; the next will be a smaller vessel with only the engines, boilers, and magazine protected; and the last will be a small shallow-water gun-boat, with one gun protected by a shield in front. But as far as a sea-going fleet is concerned, the engines, boilers, and magazine must be protected; and it is this indispensable requirement which makes an effective ship of war really a very large one. It seems to be agreed that 14 knots an hour is the minimum speed of fighting vessels of war for the future; but this speed cannot be got in a vessel under 200 feet long, and for that purpose the lines must be very fine. In order to carry the engines and boilers, which must be protected, the ship must be 60 feet longer; and in order to carry also a coated battery of 10 guns it will have to be 40 feet beam; and even then the vessel is only partially coated.

It will thus be seen that the large size of vessels which are to be entirely coated, and the mere partial coating of smaller vessels, are equally inevitable. Both are the results of unalterable laws, in the adoption of which there is no choice. This point has to be insisted upon the more strongly, because the question has sometimes been considered as if both the size of vessels and the extent and nature of their armour were matters of free choice. Such vessels are inevitably of enormous cost, and therefore too much pains cannot be bestowed on their mechanical design and the structure and durability of their armour.

The consideration of armour resolves itself into three principal questions:—first, what is the best kind of armour merely to resist the impact of shot; for which purpose the armour may be considered to be simply hung on the side of the ship, in no way contributing to the strength of the structure but merely as dead weight hanging on the hull. Secondly, what is the best way of forming the structure of a ship entirely of iron, with a view of employing the whole strength of the iron for the purpose of rendering the structure of the ship as strong as possible; making the vessel only so far shot-proof as the nature of the structure will admit, and considering resistance to shot a secondary object. In the first of these methods armour plates are hung on an already finished ship; in the second a ship is built up of

thin plates in such a way that these plates may afford as much protection as their weight can give. It remains to be considered however, thirdly, whether the thick armour plates and the thin ship plates could not be so combined together in the structure of a ship as to give that ship all the benefit of them both as armour plates and as integral parts of the strength of the ship.

The first of these questions is easily disposed of. In the original floating batteries of 1854 an ordinary wooden hull of a ship was covered with iron plates weighing about 3 tons each and 4 inches thick, tacked on by through bolts of 1½ inch diameter, slightly coned and countersunk on the outside with nuts on the inside, perforating of course the sides of the vessel. It is in this simple and rude manner that the six vessels now building by the Admiralty are coated over, with 4½ and 5½ inch armour plates. The armour of the French wooden vessels is also fixed in this manner, except that wood-screws have been substituted for through bolts and nuts, as shown in Fig. 2, Plate 77, which represents a section of the armour of "La Gloire," the first constructed of the armour-plated ships.

The "Warrior," the first English armour-plated ship, is also coated on this principle, as shown in Fig. 3, which is not affected by the circumstance of this vessel having an iron skin.

The first reliable experiments made in this country on armour plates were those against the side of the "Trusty" in 1859, of which Admiral Halsted has left a valuable record. The armour, shown in Fig. 4, Plate 77, consisted of 4 inch iron plates fastened to the side of the vessel, which was equal in scantling to that of a 90 gun ship. The general result of these experiments was that out of more than 25 shots, fired from Armstrong, Whitworth, and ordinary 32 pounder guns, only two shots pierced the armour at the joints of the plates, and these were then so spent that they dropped on the deck of the ship without reaching the other side. It is not known that any experiments were made on the armour of "La Gloire"; no doubt the actual experience gained from the iron-coated floating batteries at Kinburn was considered of more value than any which could be obtained from firing against a target under circumstances that could scarcely occur in actual warfare.

The "Warrior" target, Fig. 8, Plate 77, like the plating of "La Gloire," was based upon the experience gained by the French floating batteries at Kinburn, and ½ inch was added to the thickness of the plates as an allowance for the improvements in artillery, making 4½ inches total thickness. The plates were wider, and the iron skin was placed behind, forming the side of the iron "Warrior." This target was subjected to the fire of the ordinary Armstrong and smooth bore guns; the plates were driven in from the bolt heads and were bent and buckled in a manner that proved their admirable qualities, but the bolts were not broken, except when struck by shot, and the skin remained intact. This was the great triumph of armour plating, which proved that the iron-coated ships then in existence were invulnerable under circumstances very unlikely to be reached in an actual naval battle. Subsequently experiments were tried with the 156 pounder gun, and the three shots fired at the target punched a clean hole through the armour plate, and lodged in the backing, but did not penetrate the iron skin behind.

In the second method of constructing iron war ships, the best structure of the ship exclusively has been kept in view, and it has been endeavoured by increasing the thickness of the structure to render it shot-proof, without sacrificing any of the materials for that purpose but retaining the use of their whole strength in the ship. This was a very likely course for either an engineer or a shipbuilder to follow, and those who took up the subject from a mechanical point of view have more naturally adopted this system, which may be called the structural system; while the artillerist took up the former plan of simple iron armour, neglecting structural considerations. The principal applications of this second system are shown in Figs. 5, 6, and 7, Plate 78.

Experiments on armour plates were made in the United States at the beginning of the present century by Mr. Stevens, the father of the present system of armour-plated ships; and the "Stevens Battery" shown in Fig. 5, Plate 78, was constructed at a later period by the American government in consequence of those experiments. The ship was only half finished when its construction was discontinued; but

since the agitation of this question in America several experiments have been tried to test the peculiarities in the construction of this vessel, by subjecting a target of similar construction to the fire of the heaviest American naval guns. This armour is 6¾ inches thick in all, being composed of a 2 inch plate with a number of ⅝ inch plates behind it. The "Stevens Battery" like the "Warrior" is an iron ship, and between the iron skin and the armour there is a timber backing of 14 inches of locust timber. The target was placed on a slope of 27½° to the horizon, and fired at from a distance of 220 yards by a 10 inch service gun weighing 88 cwts., and subsequently by a Parrot rifled gun of 6½ inches bore weighing 86 cwts. The shot from the 10 inch service gun was solid spherical shot weighing 124 lbs., with a charge of 11 lbs. of powder. The deepest indentation made by this shot in the armour was 1¾ inch. Only 100 lbs. shells were fired from the Parrot gun, with 10 lbs. of powder, and they made an indentation only 1 inch deep. The slight effect produced upon the Stevens armour must be attributed to the great angle at which it was placed and the low velocity which 124 lbs. shot would have when fired with only 11 lbs. of powder. The Americans however still believe that a number of thin plates properly backed are better able to resist shot than one plate of equal thickness, which can only be considered to arise from an inability at present to forge or roll thick soft and homogeneous plates of large dimensions.

The armour of the "Merrimac," shown in Fig. 6, Plate 78, although it was designed simply for resisting shot, must necessarily from its peculiar formation add to the strength of the ship. It was not formed as is generally supposed of railway bars, but in a manner much more effective and ingenious. Bars of iron 6 inches wide and 1½ inch thick were placed vertically on the side of the ship, and another outer layer of bars of the same width but 2½ inches thick crossed the lower layer at right angles, the whole being bolted at each intersection to the side of the ship by ¾ inch bolts or screws. This armour seems to have stood remarkably well against the heaviest shot of the ships of war to which it was exposed, but fired at low velocities; for as far as it is known, no shot fired from the "Congress" or the "Monitor" pierced the side. It forms probably

the cheapest armour that can possibly be constructed, and has been introduced for fortifications by Captain Inglis, where weight is of no consequence and cost is everything. In the armour for ships of war however the case is precisely reversed.

In Fig. 7, Plate 78, is shown a section of the target constructed by Mr. Hawkshaw, who was one of the first to see the important advantages to be derived from the substitution of a structure of thin iron plates in place of the thick armour plate with wood backing, provided an equally effective resistance to shot could be obtained. This target consisted of twelve $\frac{3}{4}$ inch plates with a 2 inch plate on the outside, forming 11 inches thickness of iron altogether, the whole being rivetted together or tied by $1\frac{1}{4}$ inch screws tapped through all the plates at 8 inches pitch. Only a few shots were fired at the target, but the trial of it was a valuable experiment, and the result proved that future ships of war could not be formed of thin plates alone, though the question of iron backing still remained open.

Having now considered armour without strength and strength without armour, the third method of construction comprises the plans devised in the belief that nothing but thick armour plates perfectly solid can be shot-proof. In this conviction it has been attempted to connect the iron armour directly and immediately with the iron hull of a ship, so as to avoid wood backing with its rapid decay, its bad fastening and its bad structural qualities, and so as to make the entire hull and armour one homogeneous mass of iron, that it may as a whole possess vast strength and great durability. When this is done, the enormous cost of a fleet of large vessels will not be perilled by the chances of premature decay, and the ships will not be burdened by useless loads of material. Three plans have been tried for this purpose. One is that of the Iron Plate Committee who were to try the question of iron against wooden backing. A second plan adopted by Mr. Samuda may be called the thick plate structure, because it takes the thick plates of the armour and by scarfing them from the inside builds the upper part of the hull from the armour plates, so that they form the ship itself. The third plan by Mr. Scott Russell may be called the incorporation structure, because the hull of the ship is

here built up quite independent of the armour, and recesses are prepared in this structure into which the plates are let as into cells, and the edges of the cells are then rivetted down over the plates in such a manner as to incorporate the plates into the previously existing structure; by this plan the backing and fastening form parts of the ship, and the armour plates communicate as much strength as one uninterrupted rivet all round the edge can give them.

The Iron Plate Committee, knowing the advantages to be derived from the substitution of an iron for a wooden backing, designed the iron target shown in Fig. 8, Plate 78, which in every way except the wood backing was on the same principle as the "Warrior" target. The bolting was the same in principle, and there were ribs at the back; the only difference being that a little less material was put into the skin and a little more into the ribs. The result proved the utter insufficiency of the bolting, since 8 out of the 46 bolts holding on all the armour plates snapped off at the first round. It also proved that an iron target formed in this manner was not an improvement on the "Warrior" target so far as resisting shot was concerned. The target would probably have stood much better if the backing and framing had been exactly the same as in the "Warrior" and had had 2¾ inches of backing with 10 inch frames, instead of only 1 inch skin and ribs of twice that depth.

In Fig. 9, Plate 79, is shown the target next experimented upon, designed by Mr. Samuda. It differed from that of the Iron Plate Committee in having 5¼ inch plates, and having a very different system of framing; the chief peculiarity being a strong thick plate at the edges of the armour, through which the numerous 1⅜ inch bolts or rivets were fastened. The framing of this target proved inferior to that of the previous one, but the plates curled up in a much less degree, and stood better, excepting at the edges where they were weakened by the bolt holes.

In Fig. 10, Plate 79, is shown the target next tried, constructed on Mr. Scott Russell's plan of continuous rivetting, wholly of iron, and introducing the principle of fastening the plates without bolts. The armour plates, of 4½ inches thickness, are fitted in between wrought iron bars of the same depth which run longitudinally and

vertically along the ship's side and form part of its structure. These bars are heated at the outer edge and hammered down over the edges of the adjacent armour plates, in such a way as to form one continuous rivet passing all round the edge of each plate. There are several other plans for holding plates without bolts, which differ only in their practical execution from that now described, but their principle is the same, and the trial of this may be considered in effect as a trial of them all. The result of experiments proved that the fastening stood perfectly, and that an iron target could be constructed entirely of iron which could prevent the 156 lbs. shot fired with 50 lbs. of powder from passing through the armour.

Having now examined the effect of the shot upon all these different systems of armour plating, the writer would submit the following conclusions. In the first place a thick plate must be employed on the outside of the target. As much of the armour as practicable should be put into the structure of the ship, but it must have a thick plate on the outside. The plate must not only be a thick one, but it must also be a wide one ; in other words the fewer cracks in the armour to begin with the better. The large plates are of course very expensive, and it would be highly satisfactory if smaller ones could be made to do as well; but the 68 lbs. shot insists upon large armour plates if it is to be kept outside the ship.

The next fact, which is common to armour backed with wood and armour backed with iron, is that every bolt hole weakens the plate. A large bolt hole does not weaken it more than a small one; and if bolting is found to be the best mode of fastening, the bolts should be large and there should be few of them. The holding of the plate is of more consequence in an iron than in a wooden target, for this reason, that the iron plate is driven bodily into the wood and the only purpose which the fixing serves is to keep the plate from absolutely falling off. It would prove a very instructive experiment and would not cost much to have the "Warrior" itself subjected to the same test as its section at Shoeburyness, and then sent to sea to try the effect of the rolling of the ship upon the loosened plates; the dockyards would

also have an opportunity of finding out the easiest and most efficient method of repairing such an iron fleet.

It seems very remarkable that in the construction of armour plating such different mechanical proportions should have been adopted from those of other iron constructions, and that while 1 inch plates would be fastened together with 1¼ inch rivets or bolts, a large plate 20 feet long, upwards of 3 feet wide, and weighing more than 5 tons, should be fastened on by only fifteen 2 inch bolts. Mr. Samuda's target was far less injured and far less changed in general shape than that of the Iron Plate Committee, for the simple reason that there were a larger number of bolts to hold the plate to the skin; but they were unfortunately so close together that a couple of shots happening to strike the edges of the plates where they were weakened by the holes, one of the shots went clean through. In Mr. Scott Russell's target, constructed on the principle of fastening without bolts, the face of the target was less disturbed. The area of fastening or bolting to a given plate on this principle is 12 times that of Mr. Samuda's and 25 times that of the Iron Plate Committee's target.

The effect of shot on a target having wooden backing is to expend all its force on the armour plate, which is twisted and bent and curled up at the edges, but the iron skin remains intact. In the iron target, on the other hand, the skin and backing divide the work with the armour plate, and while the skin is broken through, the armour plate remains but little injured; and probably, although several shots did go through the two iron targets, if the firing were continued on them as well as on the "Warrior" target, the latter would be smashed in long before either of the former.

Whenever therefore ships come to be built entirely of iron, as will be the case at some future time if not now, it is submitted that they must have the following qualities: the armour plates must be wide, there must be no bolts, the fastenings must be large, and there must be an inner skin to prevent the pieces of iron from flying among the crew. Such an armour will then be superior in resisting power to that of the "Warrior," adding to the strength of the ship instead of detracting from it, having a skin uninjured and independent of the armour; and it will cost nothing for repair, but will last for ever.

It is important to glance at the power of shot fired at high velocities to penetrate iron armour, and the capabilities of the iron armour for resisting solid shot. Not much is known positively respecting this, but the following facts are tolerably well ascertained: that the 110 lbs. Armstrong shot has a velocity of 1200 feet per second, the 68 lbs. a velocity of 1580 feet per second, and the 156 lbs. a velocity of 1700 feet per second; and that these shots have respective penetrating powers of 158, 170, and 430. It is also believed that, while the penetrating power of shot is as the square of its velocity, the resisting power of a plate is as the square of its thickness. This has not been absolutely proved by experiment, but is probably not far from the truth, and any error is due to the difficulty of manufacturing thick plates as homogeneous as thin ones. Assuming then the two following data, that the 68 lbs. shot just does not pierce a 4 inch plate, and that the 156 lbs. shot just does not pierce a 4½ inch plate backed by 8 inches of iron, it can be determined approximately what thickness of plate and backing would be required to stop a given shot having a given velocity, and what size of vessel would be needed to carry such armour and also to possess all the qualities necessary in a ship of war. At present the shot fired from the most powerful gun yet made is stopped by a 4½ inch armour plate and 3 inches backing of iron, and the vessel necessary to carry such armour is of 7200 tons burden, and has a displacement of 10500 tons, a saving in weight of 600 tons being here made by the adoption of the iron backing.

Although however no shot has penetrated the strongest armour hitherto made, guns will doubtless be made to pierce it, for an Armstrong gun is now being manufactured to throw a 300 lbs. spherical shot, and guns will probably be made to throw 400 and 500 lbs. shots. On the other hand, although 4 inch armour is no longer invulnerable, it must not be considered that the thickness of armour cannot be increased because a vessel could not carry the additional weight; and the writer wishes to show that when the more powerful guns are manufactured and used in large numbers not only can the shot be stopped by armour of reasonable dimensions, but this armour can be carried by vessels of such moderate dimensions as to offer a fair prospect of the race between armour and artillery being

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continued for the next twenty or thirty years. Thus taking the gun now in progress for throwing a 300 lbs. spherical shot, which may be assumed to have a velocity of 2000 feet per second at a range of 200 yards, this shot may according to the preceding data, be stopped by a plate 7 inches thick and backed by 4½ inches of iron, as shown in Fig. 11, Plate 79. The minimum vessel required to carry such armour from end to end would be of 12000 tons burden and would be propelled by engines of 2000 horse power at a speed of 15 knots per hour; 1500 tons weight would be saved in the construction by the use of iron instead of wooden backing. Assuming still further that a gun is made to throw a spherical shot weighing 500 lbs. having a velocity of 2500 feet per second, such a shot could on the same data be stopped by

Table of Dimensions of Vessels to carry different thicknesses of Armour.

	4½ inch Armour.	7 inch Armour.	11 inch Armour.
Length of Vessel . . .	400 feet	500 feet	600 feet
Breadth	60 feet	70 feet	80 feet
Tonnage	7200 tons	12000 tons	20000 tons
Horse Power of Engines	1800 h.p.	2000 h.p.	3000 h.p.
Weight of Engines . .	1800 tons	2000 tons	3000 tons
" Armour . .	2000 "	4300 "	10000 "
" Hull . . .	2000 "	3700 "	5000 "
" Coals . .	4000 "	5000 "	7500 "
" Armament . .	700 "	1000 "	1500 "
Total displacement . .	10500 tons	16000 tons	27000 tons
Weight saved by adoption of iron backing .	600 tons	1500 tons	4000 tons

11 inch armour plates backed by 8 inches of iron, as shown in Fig. 12, Plate 79; and this armour could be carried from end to end by a vessel of 20000 tons burden and 3000 horse power, which would be under the size already attained in the Great Eastern. A comparative calculation of these vessels is given in the accompanying table.

It must be borne in mind that these vessels are coated from end to end; and smaller vessels can be made, but they must be only partially coated with these heavy plates. It will thus be seen that the days of armour-plated ships do not end with 4½ inch armour, but that there will always be a race between armour and artillery: defence has up to the present time had rather the best of it, but that will not last long. It is only to be hoped that it may long remain a friendly race between artillerists and constructors of armour.

Mr. W. Pole thought the paper that had been read gave a fair account of what had hitherto been done in the construction of iron armour for ships. As a member of the Iron Plate Committee he would explain that the reason why the Committee's target was not made with precisely the same backing as the "Warrior" target was that it was wished to try some modification in the backing, but without adding to the weight of the target, which was intended to be in other respects as much like the "Warrior" target as it could be made.

The quality of the iron of which the armour plates were to be made was a subject requiring particular attention, and the first impression was generally that the plates should be hard, and even steel-clad ships had been proposed. This was however entirely a mistake; for the results of a large number of experiments tried by the Committee with iron and steel plates of all qualities proved most decisively that, instead of being hard, the proper material for armour plates was that which was as soft and as tough as possible. Hardness, whether in

steel or iron, was quite out of the question. Steel plates had been tried, and they proved the worst that could be used for such a purpose; they broke up under the blow of the shot and became entirely useless: semi-steel was slightly less objectionable, and hard iron was the next in order. The evil was that all hard material cracked, whereas soft material bent about and became indented without cracking; and for securing a safe protection the object was to get plates that would bend without cracking. If the plates cracked, two or three shots would make them crack in different directions, so that pieces of the plates would fall off, and therefore a crack was the worst result that could be obtained. Accordingly the best kind of plate for armour was that which was as soft and tough as possible, and toughness generally appeared to go with softness. The best descriptions of iron had been tried, and when they were soft they answered very well; but even expensive qualities of iron, if not soft, would not do, because it was softness that was indispensable. Hence an important result arrived at was that expensive qualities of iron were not necessary for armour plates, for it was possible to get iron of very reasonable cost which possessed the quality of softness sufficiently for this purpose, and the great object in making armour plates was now to use iron as soft as could be got.

With regard to the thickness of the armour plates, a general hope had been entertained prior to actual trial that the plan of building up the required thickness of iron by means of a number of thin plates bolted or rivetted together would prove successful, in place of a single plate having to be made of very great thickness. In this construction of armour the proper fastening together of the plates was a point of the greatest importance; and accordingly in the target constructed on this plan, as described in the paper, the fastening was very carefully attended to: the holes were not merely punched and the rivets driven in, but they were drilled with great care by Messrs. Cochrane in the same manner as the plates of the girders made by them for the Charing Cross railway bridge; and screwed bolts tapped through all the plates were also tried. The principle of thin plates was thus tried in its best form up to a total thickness of 10 and 14 inches; but when the target came to be fired at, the result left no doubt that this plan of

construction was a failure, and that the outside plate at any rate must be a thick one and of a soft quality. The reason appeared to be that the strength of a plate to resist the blow of a shot was something like the transverse strength of a beam supporting a weight, the strength being in proportion to the square of the depth of the beam or thickness of the plate, so that a single solid plate of great thickness possessed far more resisting power than a number of thin plates making up the same aggregate thickness of metal. The size of the armour plates should be made as large as possible, in order that the extent of edges might bear the least possible proportion to the area of the plates, because if the shot struck the edges or corners of a plate they were pretty sure to break off, but if it struck in the body of the plate, away from the edge, the iron had a better chance of resisting the blow without being damaged.

A good deal of enquiry had been made as to the best method of fastening on the armour plates, whether by bolting them on or by some other plan. In the Iron Plate Committee's target the bolts soon gave way, and several plans had been tried for doing away with bolts, among which was Mr. Scott Russell's ingenious method of holding in the armour plate by a sort of continuous rivetting all round the edge, like the fastening of a picture in a frame, by means of iron ribs projecting from the backing; the plate was then put in, and the edges of the ribs rivetted over. This plan of fastening the plates had proved thoroughly successful, though it was a more expensive method; and bolting was certainly the simplest mode of fastening, but if bolts were used they must be of large size for holding on plates of so great thickness. For joining the plates to one another, the plan of grooving and tonguing was adopted in the "Warrior", because it was thought that one plate would assist the other in receiving a blow at the joint. That however was found not to be the case, for instead of one plate assisting the other, when one plate was struck it broke the other, and therefore the plates were now simply made to butt together at the joints.

As regarded the question of wood or iron backing, the general impression after all the trials was that in reality the wood backing was very useful. There had been a desire to get rid of wood backing, and trials of iron backing had been made for that purpose; but the

iron backing of the Committee's target did not prove successful, and though that in Mr. Samuda's and Mr. Scott Russell's targets had succeeded better, it was still doubtful whether there was sufficient warrant for the exclusion of wood. The wood backing appeared to answer several useful purposes: for when the plate was broken by a shot, the wood backing entirely stopped the pieces which would otherwise fly into the ship in fragments; these got imbedded in the wood and could not go further. Moreover when a shot struck a plate, if it broke the plate it generally broke out a piece in a conical form, thus extending the fracture over a much larger area at the back of the plate, so that the blow was spread over a large surface of the wood backing, which had thus a better chance of stopping the broken piece of the plate, and still preserved the inner iron skin and the ribs of the vessel free from injury. The wood backing thus rendered important service in protecting the vessel, and, even though the armour plate might be broken, the broken pieces remaining in their place imbedded in the wood still offered some resistance to a second shot striking the same spot. The object was to keep out shot and shell, and if the broken pieces were not kept in their place by the backing, the shot and shell could enter at the fractured part of the armour plate. Another advantage of the wood backing was that it acted as a buffer or cushion to prevent the jar when the armour plate was struck by a shot from extending to the fastenings of the plate. The first thing noticed in the targets with iron backing when they were fired at was the enormous vibration or jar produced by the blow, which broke out the fastenings at a great distance from the spot struck, even as far as 11 feet. The wood backing however effectually stopped the jar, and it was found that in the immediate neighbourhood of the part struck the fastenings behind were scarcely disturbed at all. He thought there was no other mode of preventing the jar and getting the required elasticity than by the use of wood, for no other material would be sufficiently strong. Springs were entirely out of the question, owing to their weakness and the excessive force that would be brought against them. Even the wood must be as hard a quality as possible, and teak was the only wood that was used for the purpose: any of the softer kinds of wood would be totally useless. A further effect of the wood backing was

that, owing to its great thickness, it distributed the force of the blow of a shot over a large extent of surface behind, whereby the injury done to the ship's side was much less than if the effect were made local by the force being confined to the spot struck. These properties of wood backing certainly appeared to give it so great an advantage that hitherto scarcely any one who had witnessed the experiments had seen reason for doing away with wood, however desirable such a step might seem from other considerations.

Mr. T. W. Plum enquired whether in Mr. Scott Russell's plan of fixing the armour plates in a frame any damage sustained in action could be repaired with facility; and what was the thickness of the ribs or rivetting pieces in the waist or narrowest part, and whether the edges of the ribs were rivetted over cold in fixing the armour plates.

Mr. N. S. Russell replied that the thickness of the ribs in the narrowest part was about 2 inches; it might be made considerably thicker if necessary, but that had not been found requisite. The rivetting was done hot, the edges of the ribs being simply heated by portable fires and then rivetted down over the edges of the armour plates by hand hammers.

Mr. C. P. B. Shelley asked how the vertical joints were made between the armour plates in this mode of fixing.

Mr. N. S. Russell explained that the vertical joints were made exactly the same as the longitudinal ones, by ribs of the same size with the edges rivetted over.

Mr. E. A. Cowper thought that in the targets in which the armour plates had been fixed by bolts to iron targets the bolts had not been applied in the best manner for holding the plates securely. In one target he had noticed that there were only a few 2 inch bolts to fix the armour plates, which were manifestly quite insufficient for the purpose, as he had pointed out previous to the experiment; and at the first shot eleven bolts were broken, and the plates became detached: in this case the sectional area of the bolts amounted to only 1-37th of the area of the plates held by them. As a more secure mode of holding the armour plates he had suggested the plan of fixing them by means of strong square-threaded screws of 5 or 6 inches diameter, screwed in at the corners and along the joints of the plates at about

15 inches pitch, each screw thus holding two adjacent plates, which would bind the plates together more strongly than any feather or tongued joint: this plan was he expected about to be practically tried on the floating battery at Portsmouth.

Mr. J. Ramsbottom enquired whether any experiments had been made with timber placed outside the armour plates, in order to diminish the blow of the shot upon the plates and prevent them from being broken. He thought 20 or 24 inches thickness of timber placed outside the plates, as thick as the timber backing in the "Warrior," might possibly have a beneficial effect in reducing the force of the blow on the plate.

Mr. W. Pole said one experiment had been tried with a few inches thickness of elm placed in front of the target, which had some slight effect in reducing the damage done to the armour plate, but not much; and it had also been proposed to put a considerable thickness of timber, as now suggested, in front of the armour plates, with a thin plate of iron again outside that to form an iron skin, but this plan had not yet been tried. It must be borne in mind however that the shot fired from a gun had a certain definite amount of power in it, received from the explosion of the gunpowder, the shot itself indeed being merely the means of conveying that power from the powder to the object struck. This definite amount of power or work contained in the shot must therefore be expended in some way or other upon the target or the ship's side, since no contrivance whatever could prevent it from being expended. It was as impossible to get rid of the power contained in the shot as it was to get rid of matter, and therefore it was a mistake to suppose that by the use of hard steel plates the effect of the blow could be annihilated altogether. Hence the object to be aimed at was not to get rid of the blow, but to receive it in the most harmless manner: and this was best accomplished by using a plate of soft iron which would admit of being knocked about and bent and indented without being actually fractured, instead of a hard plate offering an unyielding resistance, upon which therefore the work must be expended in actually breaking up the plate. It was on this account that a soft and tough quality of iron had so great an advantage for armour plates over a harder and more brittle metal. If a small

resistance were placed in front of the armour plates, by the interposition of a thickness of timber, that small resistance had of course to be overcome first by the shot, but the remainder of the power in the shot had still to be expended on the plates. An external layer of timber would also have the disadvantage of affording a lodgment for shell, and of being liable to be set on fire.

Mr. J. Scott Russell thought the explanation given by Mr. Pole of the respective merits of iron and wood backing for armour plates was a very fair statement of their relative advantages. Though himself strongly in favour of wood backing, he was nevertheless fully alive to its faults, the principal of which were the great tendency of the wood to unknown decay at uncertain periods, the difficulty of obtaining a good fastening for the armour plates, and the fact that the wood backing was a mere dead weight to be carried by the vessel, which certainly materially affected the strength of the ship. He was therefore one of those who desired to see the timber backing done away with, on account of its perishable nature and its uselessness in reference to the strength of an iron ship; and to get instead a backing incorporated with the structure of the ship, and thereby adding to its strength. The trials of the various experimental targets had been a great help in this direction, and had resulted in putting iron backing very much more nearly on a par with wood backing. As it was found that holes and bolts through the armour plates were objectionable, a trial had been made of a target having as few of them as possible; but the result showed that there was then too little fastening for the armour plates, and the amount of fastening was therefore increased, with decided advantage to the plates.

An important step was also gained by the trials of the target composed of a number of thin plates rivetted together, because it had previously been hoped that by some plan of that sort a combination of thin plates could be made which would effectually resist the heaviest shot. In this trial however the shot went clean through the whole of the twelve ⅜ inch plates composing the target, showing that no armour would do unless made in a single thickness of metal. The 4½ inch armour plates were accordingly what had now been arrived at, with as great a thickness of timber or iron backing as the ship could carry.

In addition to the iron backing which he had proposed in place of the timber backing, it was intended to have also a separate iron skin, placed at 18 inches distance at least inside the armour plates; because it was necessary not merely to make the outside of the ship as strong as possible, but also to protect the men inside against pieces flying, which was done as effectually by this means when the iron backing was used as with the much greater thickness of timber backing. If it were conceded therefore that iron backing was now nearly on a par with the wood backing in protecting a ship, which he believed to be the case, it was of the greatest importance that further endeavours should be made to turn the scale in favour of iron backing; because if this could be accomplished, the adoption of iron backing would be a great advantage in strengthening the structure of the ship, and only 2 inches thickness of iron backing would be required to replace every 18 inches of timber backing. The target already tried with iron backing was practically shot-proof against the ordinary 68 lbs. shot, and against all except the heaviest guns, which it had not been intended to resist. It did indeed prevent even the 300 lbs. shot from actually passing through the armour; but the shot did so much mischief that a battery of 300 pounder guns would soon make a hole in such a ship's side. There was no doubt that the contest between armour plates and guns would long go on as it had done at present, with the advantage alternately on the one side for a time and then on the other: so that no construction of armour that could be devised would long remain shot-proof against the continually increasing power of the guns brought to bear against it.

In his own plan of fixing the armour plates on the ship's side, by means of continuous projecting ribs with the edges rivetted over the armour plates, the fastening of the plates was now rendered so secure that it would hold them in place until they were absolutely knocked to pieces by the shot; and this was the most that could be required of any mode of fastening. With regard to repairs in this mode of construction, it certainly was not so easy to take out a damaged armour plate when fastened in this way as it was to take off one of the ordinary bolted plates; it had indeed been purposely made as difficult as possible to get out one of the plates when once put in its place;

for it was better to put in the plates in such a manner that they could not be got out by any means than to put them in so that they could be easily knocked out, for the sake of being easily replaced after they had been knocked out. If this secure method of fastening the plates enabled a ship to fight a hard battle safely and win it, there could be small ground for complaint that it was hard to get the broken plates out in order to put new ones in for the subsequent repairs.

Mr. N. S. Russell observed that although the repairs would certainly be more troublesome and expensive when the plates were fixed by the new plan of continuous rivetting, it was not impossible to repair them; but the question of repair was a secondary consideration, and in the case of the "Warrior" target the plan of dovetailing the plates into one another had been adopted, in spite of the difficulty thereby occasioned of removing a damaged plate at the water's edge, which could not be taken out without removing all the layers of plates above. The plan that had been suggested of fastening the plates by large screws inserted along the joints appeared to be the same in principle he thought as the other plans for fastening without the use of through bolts in the centre of the plates; and independently of the practical difficulty of cutting a thread of 6 inches diameter by hand in a ship's side, the area of fastening in this plan amounted to only about 16 square inches section of bolt for every 15 inches length of joint when the screws were placed at 15 inches pitch; whereas in the plates held by continuous rivetting the holding area along the edges was 34 square inches for every 15 inches length, the edge of the projecting ribs being rivetted down so as to cover more than one inch width of the edge of the plates.

Mr. E. J. Reed thought that in the present transitional state of the question between armour plates and guns there could not be much objection to a few wooden ships being built at the present time for the fleet, which would be perfectly good for fighting for the next few years; and then when this rivalry had gone on through that time the ultimate construction of ship might be introduced, of whatever character it might be. In designing an iron ship he would be quite prepared to sacrifice some of the resisting power obtained by the present armour plates and timber backing, for the sake of securing

the great structural strength given to the vessel by Mr. Scott Russell's plan of armour with iron backing. Hitherto however he did not think any vast change was called for in the construction of armour-plated ships: for one of the ordinary 50 gun frigates could now be made perfectly secure by means of armour plates 4½ inches thick extending down below the water line, backed by about 3 feet of solid timber, and provided with a battery of twelve of the heaviest guns that had been produced during the last year; this battery could be secured not only by the external armour on the sides of the vessel, but also by similar armour on the transverse bulkheads. The frigate thus equipped would he believed be a perfect sea-going ship, which could go out as securely as the "Warrior" or any other iron-plated ship, the only penalty incurred by the additional weight carried being about 15 inches extra draught of water and half a knot per hour less speed: and he had no doubt that the other wooden ships already existing in the fleet could in the same manner be made thoroughly efficient for fighting actions, by carrying a few very heavy guns fully protected instead of a large number of unprotected guns.

With regard to the quality of the iron of which the armour plates were made, he had observed that where the iron was of a superior quality the cracks produced by the shot were less than where the quality was inferior: and a plate of hammered iron from the Thames Iron Works, tried at Portsmouth, had several 68 lbs. shots sticking in it as they would do in any soft material like putty, and the iron was not starred with cracks at the places struck. In other plates also from the same works it was found that the cracks made by the shot did not as a rule go to the bolt holes, even where they went round and in the neighbourhood of the holes; and wherever a crack did happen to go to a bolt hole, it almost invariably stopped there. This fact could not be taken as in favour of bolt holes in preference to some other mode of fixing without holes through the armour plates, but it showed at any rate that the bolting sometimes did no serious mischief to the strength of the plates. At present the question of the method of fixing appeared to lie between the plan of through bolts and that of continuous rivetting; and he did not think a better plan could be found than the latter, if it were decided to do away with bolts altogether.

The CHAIRMAN concurred in thinking that in the present state of uncertainty with regard to armour-plated ships the best thing to be done was to make use of the wooden ships already existing, by coating them with armour plates. In the "Warrior" target he thought very much of the strength was to be attributed to the inner iron skin and the vertical ribs forming the framing of the target, without which its resisting power would be greatly diminished. For the strain produced by the blow of a shot diverged in a conical direction from the point struck; and in the "Warrior" target the 4½ inch armour plate was backed by about 20 inches of teak, with two layers of iron behind of 1½ inch thickness together, all of which was supported at short intervals by strong beams of double angle iron, corresponding with the vertical ribs of a ship: so that a blow struck at any spot on the armour plate was distributed over a large area at the back, and the effect was received by a large extent of the strong angle iron framing. Accordingly up to the present time no target had been produced which had as great resisting power as the "Warrior" target constructed in this manner.

He proposed a vote of thanks to Mr. Russell for the paper, which was passed.

The CHAIRMAN moved a vote of thanks, which was passed, to the Local Committee and the Honorary Local Secretary, Mr. Charles Cubitt, for the excellent arrangements they had made for the meeting of the Institution in London, and the handsome reception they had given to the Members on the occasion.

He also proposed a vote of thanks, which was passed, to the Council of the Royal Institution, for their kindness in granting the use of the Lecture Theatre for the purposes of the meeting.

The Meeting then terminated. In the evening the Members and their friends were entertained by the Local Committee at a Conversazione held in the Egyptian Hall at the Mansion House, by the kind permission of the Lord Mayor, where a collection of machinery, engineering models and drawings, specimens of manufactures, microscopes, &c., was exhibited.

On Friday, 4th July, an Excursion of the Members took place to the Royal Gun Factory and Arsenal at Woolwich, where through the special arrangements kindly made by Mr. Anderson they were enabled to witness the several processes of the manufacture and proving of guns and the other operations carried on at the Arsenal.

In the evening the Members and their friends dined together at the Crystal Palace, Sydenham.

PROCEEDINGS.

6 November, 1862.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 6th November, 1862; Charles F. Beyer, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Annual Meeting.

The following Members were nominated by the meeting for the election at the Annual Meeting :—

PRESIDENT.

Robert Napier, ... Glasgow.

VICE-PRESIDENTS.

(Six of the number to be elected.)

Charles F. Beyer,	Manchester.
Alexander B. Cochrane,	Dudley.
Edward A. Cowper,	London.
James Fenton,	Low Moor.
Benjamin Fothergill,	London.
Thomas Hawksley,	London.
Robert Hawthorn,	Newcastle-on-Tyne.
Sampson Lloyd,	Wednesbury.
Henry Maudslay,	London.
John Ramsbottom,	Crewe.
C. William Siemens,	London.

COUNCIL.

(*Five of the number to be elected.*)

Frederick J. Bramwell, . .	London.
Daniel K. Clark, . . .	London.
William Clay, ...	Liverpool.
John Fernie, . . .	Derby.
Sir Charles Fox, . . .	London.
Thomas Greenwood, . .	Leeds.
Gilbert Hamilton, . . .	Birmingham.
Edward Humphrys, . .	London.
James Kitson, ...	Leeds.
John Vernon, . . .	Liverpool.

The Chairman gave notice that it was proposed by the Council to move a resolution at the ensuing Annual Meeting:—"That all Members who have filled the office of President of the Institution be ex officio permanent Members of Council, under the title of Past Presidents."

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Joseph Barrow, ...	Leeds.
Edward Barton, . . .	Sheffield.
Henry Wollaston Blake, . .	London.
Alfred Blyth, . . .	London.
Joshua Field, ...	London.
Douglas Galton, R.E., . .	London.
Thomas John Haynes, . .	Cadiz.
William Edward Newton, .	London.
Alfred Stansfield Rake, . .	Derby.
Robert Richardson, . .	London.
Joseph F. Strong, . . .	Allahabad.
Richard Taylor, . . .	London.

HONORARY MEMBER.

William Whitehead, . . .	Sheffield.

The following paper was then read:—

ON A PACKING FOR PISTONS OF STEAM ENGINES AND PUMPS.

By Mr. GEORGE M. MILLER, of Dublin.

This Packing consists of two rings, pressed outwards against the cylinder by the pressure of the steam as it acts on the alternate faces of the piston, without the use of any springs. The construction of the piston is shown in Figs. 1, 2, and 3, Plate 80, as used by the writer in the Locomotive Engines on the Great Southern and Western Railway of Ireland. The piston is of cast iron, 2 inches in thickness and 15 inches diameter. Two square grooves A A are turned in the edge of the piston, $\frac{3}{8}$ inch in width and $\frac{3}{8}$ inch apart, and a corresponding steel ring is fitted into each groove, the rings being divided at one part with a plain butt joint, and sprung over the piston into their places. Two small holes B B, $\frac{1}{8}$ inch diameter, open from each face of the piston to the bottom of the nearest groove, whereby the steam is admitted behind the packing ring and presses it out against the cylinder so long as the steam is acting upon that face of the piston. The alternate action of the two rings is continued as long as the steam is acting on the piston, one of them being always pressed steam-tight against the cylinder.

In Figs. 4, 5, and 6, Plate 81, is shown one of the pistons with brass rings which are $\frac{3}{4}$ inch width and $\frac{7}{16}$ inch thickness, the piston being $3\frac{1}{2}$ inches wide.

Another form of the piston has been used in cases where the piston is desired to be flush on both faces or to fit a cylinder with flat covers: in this a circular flat head forged upon the piston rod is fitted between the turned faces of the two halves of a cast iron piston, which are held together by turned pins rivetted over, forming a hollow piston flush

on both faces, fast upon the piston rod, and without any loose part besides the two packing rings.

The ends of the rings where divided are made with a butt joint, as in Fig. 3, Plate 80; or with a lapped joint, as shown in Figs. 7 and 8, Plate 81. The piston body is turned to pass through the cylinder easily; and the joints of the rings have been found to be practically steam-tight. In some cases the joints have been tongued, as shown in Fig. 6, but in the writer's experience this has not been found requisite; the butt joint has invariably worked well, whilst it has the advantage of perfect simplicity of construction. In pistons where the packing ring travels over the opening of the cylinder port a small stop is fixed in the bottom of the groove, entering a short slot in the packing ring, to prevent the ends of the ring coming opposite the cylinder port, but still leaving the ring free to travel round a little in the piston grooves: but it is preferred for the packing rings not to travel over the cylinder ports.

Another form of joint for the packing rings is shown in Figs. 9, 10, and 11, Plate 82, intended to be used in a stationary engine with cylinder 16 inches diameter. A brass stop piece C, 1 inch thick and 4 inches long, is placed in a recess at the back of the joint, serving as a cover to the joint at the top and bottom by projecting ⅛ inch in thickness on each side of the ring.

These steam-packed pistons have been used more than seven years in the locomotives of the Great Southern and Western Railway, and have proved so satisfactory and advantageous that their use has been extended to all the 94 locomotives working upon that line. The following are the results of the working in the engines running from Dublin, as regards the durability of one set of rings, the period of their wear, and the mileage of the engines whilst wearing them out. Nineteen engines working with one set of steel rings averaged 33,020 miles and 16½ months' running, one engine having worked for 3 years and run as much as 98,073 miles with one set of packing rings. Five engines working with one set of brass rings under the same circumstances averaged 30,986 miles and 19 months' running, the greatest work amongst them being 2½ years and 43,197 miles.

Twenty other engines with steel rings which are still in use have also averaged 40,444 miles and 21 months' work, one of these having worked for 3¼ years and run 94,399 miles with the original set of rings.

The general result of the above is that one set of steel packing rings have lasted 37,000 miles and 19 months' work, and one set of brass rings 31,000 miles and 19 months' work, the difference in durability being about 16 per cent. in favour of the steel rings. In some of the individual cases of the pistons with steel rings, a very considerable variation from the average result of 37,000 miles is found in the durability of the packing rings, some of them having lasted 2¾ times the average and some only as much below the average. In the case of the brass rings the variation is not so great, amounting to 1¾ times the average in the highest and about as much below the average in the lowest. This variation in wear has not been fully accounted for: it may have occurred from a different character of metal in the cylinders, from priming of the boiler, and from the presence of grit in the water; but the writer has reason to believe that the rings have been frequently put in to work and set with a pressure upon the cylinder from their own elasticity, thus causing a source of wear. It is found the best plan to turn the rings to the exact diameter of the cylinder, and to put them in without any spring upon them, so that they are not subjected to any wear except when the steam is acting on them. The steel rings are now slightly tempered, to admit of their being sprung into the grooves without altering their form. In all these pistons the steel packing rings were ⅜ inch thick originally and ⅜ inch wide, and they were worn down to about ⅛ inch thick in the thinnest part before being removed. The brass rings are worn down from $\frac{7}{16}$ inch until they are ⅛ inch thick. Specimens are exhibited of steel rings from four engines that have worked 38000, 61000, 84000, and 96000 miles respectively since first put into the pistons. It must be remarked that when opportunities occur, as when engines are under repair, the rings are taken out and re-set to the size of the cylinder.

It is found in practice that two steam ports of ⅛ inch diameter are quite sufficient for each of the steel packing rings, drilled in the

position B B shown in the drawings, Plates 80 to 83. The rings must be made to fit easily in their grooves, so as to move freely, with a clearance of $\frac{1}{16}$ inch at the bottom of the grooves for the steam to pass round behind the rings. No difficulty has been experienced from the steam passages becoming stopped up with a moderate use of tallow in the cylinders.

The use of this piston packing in locomotive engines has been productive of economy by reducing the friction and by prolonging the wear of both pistons and cylinders. It will be observed that only one ring is in action at the same time, and that when the steam is shut off, as in descending inclines and approaching stations, the piston is free to move without any friction. The cylinders of the four engines from which the specimen rings exhibited have been taken show a highly polished surface, are very little worn, and are nearly parallel throughout. The operation of putting in these rings so as simply to fit the cylinder is extremely easy, whilst great care and skill are required in giving springs the requisite degree of elasticity and in making them maintain it.

A set of brass packing rings is also exhibited, taken out of the pistons of a pair of vertical Stationary Engine cylinders at the Dublin railway station, in which they have been in constant work for the last four years, with a pressure of 50 lbs. steam. The diameter of the cylinders is $19\frac{1}{8}$ inches, and the rings were originally $\frac{5}{8}$ inch thick and $\frac{3}{4}$ inch wide; they are now worn down to $\frac{5}{16}$ inch thick.

A number of stationary engine pistons are working with these packing rings, and they have proved very durable and thoroughly satisfactory, giving an advantage in reduction of friction, and in preserving the cylinder face in perfect condition. In one case of the engine of the Oldbawn Paper Mill near Dublin, with vertical cylinder 18 inches diameter and $2\frac{1}{2}$ feet stroke, working with 50 lbs. steam, the cylinder had previously been worn considerably out of truth and much grooved, and one of these pistons was put in having two steel rings of $\frac{3}{4}$ inch width and $\frac{3}{8}$ inch thickness, and was in constant work for four years without the packing rings requiring renewal. They have lately been taken out for examination, and were found to be still

¼ inch thick; and the cylinder from its previous defective condition has been brought completely to truth throughout, with a highly polished surface.

These packing rings have also been used for four years for Pump Buckets, and have proved very satisfactory. In one case of a double-acting pump 8 inches diameter, shown in Fig. 12, Plate 83, the two packing rings A A are of brass, ⅜ inch wide and $\frac{5}{16}$ inch thick, and are pressed out by the pressure of the water acting at the alternate faces of the bucket through two ports B B, ⅛ inch diameter, similar to those in the steam pistons. This pump had two years' constant work at quarries and bridge foundations upon the Great Southern and Western Railway, before the packing rings required renewal.

In the case of single-acting pumps the bucket has only a single packing ring with ports opening from the upper side, as shown in Fig. 13, Plate 83, which represents a pump bucket 5 inches diameter that has been working constantly for 2½ years at a station on the railway near Dublin. This bucket is now exhibited, having been taken out for this purpose: the packing ring A was originally ½ inch wide and ¼ inch thick, and has worn less than $\frac{1}{16}$ inch in the 2½ years that it has been working up to the present time. As the diameter in this case is too small to allow of the ring being sprung over the body of the bucket into its place, it is put in by means of a junk ring D screwed on at the under side of the bucket, as shown in the drawing.

An application of the same construction of packing that has also been made to the gland packing of a 9 inch pump plunger is shown in Fig. 14, Plate 83; in which two brass packing rings are used, ½ inch wide and ⅜ inch thick, just like the piston packing rings, except that they act in the opposite direction, being pressed inwards upon the plunger by the pressure of the water through the ports B B.

Mr. Miller exhibited specimens of the steel packing rings from the pistons of four locomotives which had run from 38000 to 96000 miles; and also the brass packing rings from the pistons of the stationary engine, together with the bucket of the 5 inch single-acting pump referred to in the paper.

Mr. J. Fernie was glad that the subject of packing rings for pistons, which were such an important part of a steam engine, had been brought forward in the paper just read. He observed that steel packing rings had not been found to wear well in other instances in which they had been tried, and moreover they cut the cylinders; and he enquired whether the cylinders in which the steel rings had been working for so long a time were made of a very hard quality of metal.

Mr. Miller replied that the cylinders were cast as hard as they could be made, consistently with allowing of the subsequent boring. The packing rings were made of common shear steel, and sometimes wore down irregularly in thickness, but in many cases the wear was regular.

Mr. J. Fernie asked how the steel rings were made.

Mr. Miller said the steel was rolled in lengths of the required shape, but slightly tapering in section from the outer to the inner face, so that when bent into a circle the two edges of the ring became nearly parallel, giving the same depth of ring throughout its whole thickness. The bar was then bent in a miniature plate-bending machine, hammered to the size of the cylinder, and fitted into the groove in the piston by simply filing, without any other work being spent upon it. At first the rings were turned in a lathe out of a steel cylinder and then cut across, but it was found better to get steel rolled of the proper section for the purpose, and afterwards bend it and fit it by filing.

Mr. F. J. Bramwell enquired what amount of spring was given to the packing rings before they were put in their place, and whether the piston had ever been tried without admitting the steam behind the rings, in order to see how far it would be rendered steam-tight by the pressure of the rings alone without the steam behind them.

Mr. Miller explained that the packing rings were put in without any amount of spring of their own, being made no larger than the

diameter of the cylinder, in order that there might be no pressure against the cylinder and therefore no wear whilst running with the steam shut off.

Mr. J. Fernie remarked that the steel packing rings in Mr. Ramsbottom's piston, generally three in number, were set with a certain amount of spring in themselves, by which the required pressure against the cylinder was obtained; and that plan required the cylinders to be of rather hard metal to stand the constant pressure in working. He enquired whether the brass packing rings that had been used had been adopted for the purpose of working in soft cylinders.

Mr. Miller said the rings first used with this mode of packing were brass, and after some time a set of steel rings was tried, the experiment being proceeded with rather cautiously from fear that the steel rings might cut the cylinder; but it was found they did not do so, if fitted in without any spring whatever in the rings themselves, but with only the steam behind pressing them against the cylinder. The result was that it very rarely occurred now that a cylinder required reboring: the cylinders not only preserved a fine smooth surface, but kept more parallel than under the old modes of packing the pistons. The reason of using the steel rings and discarding the brass was that the steel lasted about twice as long.

Mr. J. Fernie asked what was the weight of the steam-packed piston for a locomotive cylinder of 15 inches diameter.

Mr. Miller replied that the weight of a piston of that diameter was 64½ lbs. without the rod, which was 2⅜ inches diameter: the piston was 2 inches thick.

Mr. J. Fernie said they had tried some pistons on the Midland Railway on this principle of packing by the pressure of the steam behind the rings; they were wrought iron pistons forged solid on the piston rods, and the packing rings were of brass ½ inch square in section. A very long mileage was got out of these rings, but it was found that with solid pistons there was a great deal of trouble from the necessity of getting the crossheads off to draw the piston out, whenever it was wanted to do anything to the piston or look at the packing rings; and they had therefore now gone back to the old fashioned piston with a

junk ring bolted on the face for getting at the packing rings. The bearing surface was now reduced to 1 inch in the pistons; there were two ½ inch packing rings, and these gave a longer mileage than used to be got out of two 1¼ inch rings. A great width of bearing surface was not required, but a small bearing surface was preferable, provided the rings were made to fit the cylinder accurately all round; and Mr. Ramsbottom certainly had the credit of having first called attention to the advantage of narrow packing rings well fitted. The 16 inch piston now used in the Midland locomotives weighed 1¾ cwt. including the piston rod, having been reduced in weight 28 lbs. below the previous make, in consequence of which a longer mileage was got out of the packing rings; the wear of the cylinders was also greatly reduced, a highly polished surface being maintained. Formerly there used to be a great deal of trouble from the cylinders wanting reboring, but now with the narrow packing rings and light pistons this was quite removed. He thought highly of the steam-packed piston, and the results obtained in the durability of the packing rings were certainly very extraordinary, 90,000 miles far exceeding any mileage previously attained. In his own experience about 20,000 miles was the durability of a set of ½ inch square brass rings, and then they would want setting up twice or three times during that period. He enquired how often the steel packing rings had been set up before they were worn out.

Mr. Miller said the packing rings had not been examined and set up at stated times, but whenever the engine happened to be in for casual repairs the piston was taken out, and the rings examined and set out if required, by slightly hammering them all round to bring them again up to the exact diameter of the cylinder: or they were replaced by new rings if worn out. The results of mileage with the different sets of rings were drawn from a return of the exact mileage of all the engines that were working under his own observation.

Mr. J. Fernie enquired whether the application of the packing rings which had been described for the gland packing of a pump plunger had been tried also for the stuffing-boxes of piston rods in steam engines, in which the want of a good packing was a source of great wear and tear.

Mr. MILLER replied that he had not yet tried the packing for that purpose.

Mr. F. J. BRAMWELL enquired whether the brass rings in the Midland piston that had been referred to were set to a larger diameter than the cylinder, and how the pressure against the cylinder was obtained, as he supposed the brass rings would not keep their elasticity long by themselves; and he asked what amount of pressure they exerted against the cylinder.

Mr. J. FERNIE replied that the brass packing rings were $\frac{1}{2}$ inch square in section, and the two rings were turned $\frac{1}{8}$ inch larger than the cylinder; a wrought iron ring $\frac{3}{16}$ inch thick was placed inside the packing rings, and then inside that a single light hoop spring of steel $\frac{1}{8}$ inch thick at the ends and $\frac{3}{8}$ inch thick in the centre, so as to maintain a uniform pressure all round the brass packing rings. The inside spring had its ends hooked, and was easily got out with a pair of tongs; and the pressure it produced on the packing rings being very light, the friction against the cylinder was so small that the piston could be pushed along in the cylinder by hand; but when the packing rings were set up by separate springs, as in the old construction of piston, it required a pinch bar to be used for the purpose of moving the piston in the cylinder.

Mr. F. J. BRAMWELL enquired whether the pressure of the packing rings against the cylinder was as great per square inch when springs were used as with the full pressure of the steam behind the rings in the steam-packed piston.

Mr. J. FERNIE could not say what amount of pressure per square inch was obtained with the springs, but in the steam-packed piston he expected the pressure behind the rings would be attenuated by the steam having to pass through only two holes of very small size, so that the full pressure would not be exerted upon the rings.

Mr. F. J. BRAMWELL remarked that if that were the case the pressure would be greater in a long stroke than in a short one, if there were no leakage of steam past the edge of the rings, as the steam would have more time to get behind them; or else the holes must be made smaller for a longer stroke. But he thought probably there would always be nearly the full pressure of the steam behind the

rings that there was in the cylinder, judging from the quickness with which the steam filled the cylinder of an indicator through a small orifice.

Mr. Miller said that with the brass packing rings first tried the holes behind the rings were drilled $\frac{1}{4}$ inch diameter, but that size was found too large, and they were therefore reduced to $\frac{1}{8}$ inch diameter, which proved to be sufficient for obtaining the required pressure to make the piston steam-tight in the cylinder. The pressure was greatest at the commencement of the stroke and decreased after the steam was cut off in the cylinder; and the consequence of this diminution of pressure together with the greater speed of the piston at the middle of the stroke was that the surface of the cylinder wore more parallel and to a smaller extent than when springs were used, because the latter exerted an equal pressure throughout the entire stroke and were always in action whether the steam was in the cylinder or not.

The Chairman enquired whether the piston body was turned much smaller than the cylinder or only an easy fit.

Mr. Miller replied that the piston body was turned down to about $\frac{1}{32}$ inch smaller diámeter than the cylinder, so as to pass easily through it.

Mr. D. Joy observed that in a locomotive piston with cast iron packing rings of light section he had found the pressure against the cylinder to be rather less than $3\frac{1}{2}$ lbs. per square inch. He thought cast iron was better for the packing rings than either brass or steel, being harder than brass and not so likely to cut the cylinder as steel might be. Turned cast iron packing rings $\frac{1}{2}$ inch or $\frac{5}{8}$ inch thick could readily be sprung over a piston 16 inches in diameter, and would be strong enough to maintain their elasticity.

Mr. Miller said he had not tried cast iron for the packing rings, as they were so small that he thought it would hardly be safe, and if made as much as $\frac{1}{2}$ inch thick they would be too stiff to be sufficiently acted upon by the steam behind. In a stationary engine piston of larger diameter cast iron packing rings might do well enough.

Mr. J. Fernie asked whether the steam-packed pistons worked equally well in running down hill as on level lines of railway.

Mr. Miller replied that there were many inclines on the line, the maximum gradient being 1 in 100, and the pistons were found to work perfectly well down hill. They had the advantage of being free from pressure of the packing when the engine was running with the steam shut off, at which time consequently there was no lubrication for the piston.

The Chairman enquired whether there had been an opportunity of comparing the working of the new pistons with any of the older forms of pistons that were still used on many railways, and whether they required as much looking after as the old pistons. The ordinary make of pistons with a junk ring or loose plate bolted on gave convenience for examining the packing rings without drawing the piston out of the cylinder as had to be done with the new pistons, and it would be an inconvenience therefore in the latter if the packing rings had to be looked at frequently.

Mr. Miller said they had now discarded all the old pistons, finding them so expensive to maintain, and the new pistons required much less looking after. There was no necessity for examining them at particular times, as they remained steam-tight without any attention for many months' working; but whenever the engine was undergoing repair, advantage was taken of the opportunity to draw the pistons out and set out the rings again if they were worn. Previously with only 50 engines running four men were constantly at work repairing the pistons, but now with 94 engines running one fitter kept all the pistons in order.

Mr. F. J. Bramwell asked whether the packing rings filled out to the size of the cylinder as they became worn, or whether when the steam was off they returned to their original inside diameter.

Mr. Miller replied that when taken out after a great deal of wear the packing rings were slightly smaller in diameter than the cylinder, and then required setting out by hammering. Sometimes they wore perfectly equally all round, and sometimes more at the ends or in the middle.

Mr. J. Wright remarked that in two double-acting forcing pumps of 8½ inches diameter which he had erected at the Bishop Auckland Water Works, for pumping the water under a head of

270 feet, he had adopted the same plan of packing for the solid piston, using two steel packing rings with the water pressure acting behind them: these worked well during the 2½ years that the engines were under his observation, requiring no repairs during that time. Similar packing rings were used for the steam cylinders. One great advantage in this plan of packing was that only one packing ring was in action at a time, while the other ring which had no pressure upon it did not rub against the pump barrel or cylinder in the return stroke, avoiding unnecessary friction; but in ordinary pistons both rings were pressing against the cylinder constantly, which was not necessary, since the new plan of packing made the pistons tight enough for all practical purposes. He enquired whether there had been any experience of the steam-packed piston in a steam hammer, as he was about to adopt that mode of packing for a steam hammer which he was making for his own works with cylinder 22½ inches diameter and 6 feet stroke; and he thought it would be an advantage to have the piston free from the friction of the steam-tight rings when the hammer was falling, by the steam pressure being then removed from behind them.

The Chairman said he had made the piston packing described in the paper for many locomotive engines, but was using Mr. Ramsbottom's packing rings for all his steam hammers, the largest of which was 26 inches in diameter.

Mr. F. J. Bramwell said he had had some experience of Mr. Ramsbottom's packing rings in steam hammers with cylinders of 18 inches diameter, and also in a 27 inch steam hammer which gave great satisfaction; and he was consequently putting up a hammer with a 36 inch cylinder with the same mode of packing.

The Chairman asked what was the largest size of steam engine piston now at work with the new packing.

Mr. Miller replied that the largest steam-packed piston was one of 24 inches diameter made for a saw mill in Dublin. In the case of the Oldbawn engine, mentioned in the paper, the cylinder was now as good as a cylinder could be; parallel, very smooth, and true in diameter: five years ago this same cylinder was worn so badly by the former piston that it was about to be replaced by a new one; but it

was set to work again for trial with the new piston without reboring the cylinder, and had since got into the present perfect condition, the steel rings having the effect of gradually wearing away all the irregularities of the surface until it was brought to a perfect cylindrical form, when the rings would bear with a perfectly equal pressure round their whole circumference, and no further wear was perceptible.

The CHAIRMAN asked whether the half lapped joint of the packing rings shown in one of the drawings (Fig. 8, Plate 81) was used, and how it was made.

Mr. MILLER said he had some packing rings, both of steel and of iron, working with the lapped joints. The notch at each end of the ring was cut out by a slotting machine, before the bar forming the ring was bent to the shape of the cylinder. The plain brass rings with butt joints were turned out of a gun-metal cylinder, and then cut: he had also tried rings made of yellow rolled brass, rolled into bars and then bent to the shape of the cylinder, but these did not wear so well as gun-metal.

Mr. J. FERNIE said he had also tried to make packing rings out of rolled brass, by cutting it into rods of the required length and bending them to shape; but they were too soft for work, and he had to return to the cast gun-metal rings.

The CHAIRMAN remarked that after making and employing a great many different descriptions of pistons he thought the steam-packed piston described in the paper was a very good one, and it had the great advantage of being very simple in construction. Formerly it was a great object to keep the steam out of the piston, on account of the internal packing springs; but in this piston the steam was admitted inside to act as the spring upon the packing. The practical feature of the new pistons was their great simplicity of construction: but to Mr. Ramsbottom was certainly due the credit of first simplifying the construction of pistons to so great an extent. He considered the piston now described ought undoubtedly to work well, because there was so little about it to get out of order, and it could not do otherwise than prove highly satisfactory. He proposed a vote of thanks to Mr. Miller for his paper, which was passed.

The following paper was then read:—

ON MACHINERY FOR THE MANUFACTURE OF GUNSTOCKS.

By Mr. THOMAS GREENWOOD, of Leeds.

Of all the various articles into which wood is shaped by machinery few have presented greater difficulties than Gunstocks. The irregularity of their form and the intricate shaping required to receive the metallic parts of the gun have rendered so many separate operations necessary, requiring such a variety of machines, that it can scarcely be matter of surprise that gunstocks have hitherto been made by hand in all the leading gunmaking localities both in this country and on the continent: and this might have continued to be the case, had not other reasons arisen besides the economy of labour to be effected by the introduction of machinery. In military arms, where very large numbers of one pattern are required, the desirability of making all the parts interchangeable naturally suggested itself; but it required years of thought before this principle could be fully developed and practically carried out. In order to carry it out practically, it is required not only that the gunstock should be made perfect, but that each of the metallic parts should be equally perfect. Hence the manufacture of each separate part by machinery had to be studied and accomplished, involving no small amount of ingenuity to make perfectly by machinery what had hitherto been done easily and cheaply by hand, though wanting in the exactness necessary to form the parts of an interchangeable gun. Possibly if the demand had not been for a national purpose the manufacture of machine-made guns might yet have been unattained: whatever the cause however, gunmaking by machinery on the interchangeable principle is now successfully accomplished.

The object of the present paper is to explain the process of making gunstocks by machinery, and to describe some of the processes in detail. To secure success there is one condition which must be rigidly

observed throughout this manufacture, namely perfect accuracy in each operation. In a manufacture where twenty operations are built upon one another, each depending for its accuracy upon a previous one, it is evident how important this condition is to success. The following is the entire series of successive operations, 23 in number, which are performed by a set of machines for shaping and finishing the stocks for rifles, each operation advancing the stock a step further from the original rough bar of wood towards its completion in the required form.

1. The upper edge of the stock is cut nearly in a line with the centre of the barrel, and is finished with an oblique cross cut at the breech; the muzzle end is also cross cut nearly to the correct length. This operation is called "slabbing".
2. The centres are made in the butt and muzzle ready for the rough-turning machine.
3. The fore end of the stock is rough-turned.
4. The butt end of the stock is rough-turned.
5. Five flat places are cut on the right hand side of the stock, and two on the left side. This operation is called "spotting".
6. The hollow bed to receive the barrel is cut out, and the tang of the breech screw is let in. This operation is called "bedding the barrel".
7. This is a hand operation, consisting in squaring the conical recess made by the cutter in the previous operation, to receive the taper projection under the tang of the breech piece; and the corner is rounded off to fit the hollow under the tang.
8. The stock is sawn to the exact length at both ends, and the butt end shaped to the form of the butt plate, by means of a revolving cutter.
9. The flat sides are planed where the lock plate is inserted, and the side caps are let in, which act as nuts for the screws holding on the lock: also the upper edges of the recess for the barrel are profiled, and the upper and under edges of the butt end of the stock.
10. The tang of the butt plate is let in, the three holes for the screws are bored, and the two end holes also tapped.
11. The corner under the tang of the butt plate is rounded off by hand.
12. The lock is bedded. The lock bedding machine is described subsequently in detail and shown in Plates 84 to 88.
13. The end of the curved recess for the cone seat where it joints against the lock plate is squared by hand.
14. The trigger guard is bedded and the screw holes drilled, and the recess for the trigger plate is cut and the stop for the ramrod let in.

15. The stock is cut under the bands from a copy, and the nose cap is let on.
16. The stock is cut between the bands. The machine for this purpose is also described subsequently in detail and shown in Plates 89 to 92.
17. The arris at the extreme muzzle end of the stock under the flange of the nose cap is taken off by hand.
18. The butt end of the stock is finish-turned in a copying lathe.
19. The fore end of the stock between the lock and the first band is finish-turned in a copying lathe.
20. The groove is cut for the ramrod.
21. The recess to receive the ramrod spring is cut out, and the transverse pin hole for fixing the spring is bored.
22. The hole for the ramrod is bored in continuation of the groove.
23. The holes for fixing the lock plate are bored, and also the screw hole for the tang of the breech screw, the screw hole for the nose cap, and the pin hole to fix one end of the trigger guard.

The Lock Bedding Machine, for performing the 12th operation of cutting out the bed or recess to receive the lock, is shown in Plates 84 to 88. Fig. 1, Plate 84, is a front elevation of the machine; Fig. 2, Plate 85, a side elevation partly in section; and Fig. 3, Plate 86, a plan with the upper portion of the framing removed.

In this machine five separate operations are successively performed to cut and shape the recess for the lock, with one fixing of the gunstock in the machine. The five cutters or drills A, Figs. 1 and 2, Plates 84 and 85, are fixed each in a vertical spindle B carried on the vertical slide C, as shown enlarged in Figs. 4 and 5, Plates 87 and 88; the drill slides C are mounted on the circumference of the circular cage D, which turns round on the vertical centre shaft E, Fig. 5. Each drill slide C has a circular or transverse motion to a short extent round the circumference of the cage D, and also a vertical motion, and is moved both transversely and vertically by the lever F provided with universal joints. A plain cylindrical driving wheel G at the top of the machine, turned perfectly true, drives each of the five drills by friction, by means of the small driving roller H on the top of the drill spindle, Fig. 3, Plate 86. The main driving wheel G runs loose on the centre shaft E, being driven by the belt pulley I above, Figs. 1 and 2. The vertical drill slides C are each held up by a coiled spring J, Fig. 5, which lifts the roller H of the drill spindle out of gear with the driving

wheel G when not in use, so that the drill does not revolve until pressed down by the handle F.

The gunstock K, Fig. 4, Plate 87, is fixed longitudinally upon a horizontal sliding table L, and is held in its proper position by a portion of a barrel and tang M sufficient to keep it firm when pressed home by the eccentric N. The horizontal table L can be moved freely backwards and forwards longitudinally by the hand lever O, Fig. 2, by means of a toothed segment gearing into a rack on the underside of the table. The centre shaft E of the circular cage D carrying the drills is supported in a frame bridging over the table L. Alongside the gunstock upon the same sliding table L is fixed the pattern P, or "former" as it is termed, made of hardened cast steel, which is an exact copy both in size and form of the recess to be cut in the stock. The shape of the pattern P is followed by a tracer R, Fig. 4, fixed parallel to the drill A in the drill slide C. Hence if the horizontal table L be moved longitudinally and the drill slide C transversely and vertically, by the combination of these three movements every part of the pattern can be traced by the tracer R, while an exact facsimile of the pattern is being cut in the wooden gunstock by the drill A. The five drills of the machine are all of different sizes, for cutting the different portions of the recess, and each drill is accompanied with a corresponding tracer of the same size. When one drill has finished its own particular portion of the work, the circular cage D is turned round by hand to bring the next drill into operation upon the gunstock: the cage is locked by a spring as each succeeding drill is brought round into position, and is then released by the foot by the treadle S. A small fan T with two air tubes blows away the cuttings from the drill and also from the pattern.

For cutting the lock recess it is absolutely necessary that the cutter and the tracer be of exactly the same size, otherwise the recess will not correspond precisely with the pattern. In order to maintain perfect accuracy of the recess cut, the sockets in three of the drill spindles are bored 1-64th inch eccentric, and the shank of the cutter is turned to the same amount of eccentricity with the cutting part. The end of the spindle nose is graduated through half its circumference into fine divisions and a zero line is made upon the cutter; and when

the cutter is new or full size, and placed so that the two eccentricities counteract each other, the cutting part is perfectly true. But as soon as the cutter has been made sensibly less by sharpening, it is turned round one or two divisions in the drill spindle, so as to impart just as much eccentricity to the cutting tool as the sharpening has reduced it in diameter, thus causing the cutter to continue to describe a circle exactly the size of the tracer.

The following are the operations performed by each of the five drills in succession in order to cut out the whole of the recess for bedding the lock. The first drill cuts out the recess to receive the lock plate; and the tracer for this operation is provided with a cross piece, which reaches across the entire width of the recess in the pattern, so as to prevent the tracer from being pushed down into the pattern lower than the depth of the lock plate. The second drill bores out the hole for the shank of the "sear", and also a hole for the sear spring screw. The third drill bores two holes for the bridle screw heads. The fourth drill cuts out the principal recesses below the lock plate, and partially cuts out the curved recess for the cone seat. The fifth drill cuts out the rear end of the recess to make room for the heel of the sear spring, and also cuts out a small notch on the lower side of the recess to receive the end of the swivel when the hammer is down. The first, fourth, and fifth drills are the three which have their shanks turned eccentric to allow of adjustment for wear; while the second and third drills, having merely to bore out plain circular screw holes, are fixed concentric in their spindles.

The operation of cutting the recess for the gun lock is performed with great rapidity by this machine, which will recess upwards of 1000 gunstocks per week. This lock bedding machine may be taken as a type of the machines arranged for copying from the interior of a pattern: several of the machines used in the manufacture of gunstocks are of similar construction.

The Shaping Machine for shaping the gunstock between the bands, which is the other machine selected for description in detail, is one copying from an exterior pattern, and performs the 16th operation of shaping the external portion of the stock between the bands.

Figs. 6 and 7, Plate 89, are a side elevation and end elevation of the shaping machine, and Figs. 8, 9, and 10, Plates 90 to 92, show its construction more in detail to a larger scale.

In this machine the pattern to be copied consists of a series of cams A A, Figs. 8 and 9, Plates 90 and 91, mounted upon a horizontal shaft immediately over and parallel to the gunstock B; and the shape of the pattern is transferred to the gunstock by the revolving cutters C mounted in the rocking levers D, at the extremities of which are the tracers that follow the circumference of the pattern cams. The gunstock B is fixed upon a bar or mandril E, which corresponds exactly with the gun barrel and fits precisely into the groove cut in the stock in one of the earlier operations to receive the barrel; and this barrel groove serves as the fixed accurate basis for the present and all the subsequent operations, as well as in the previous operation of bedding the lock, thus ensuring absolute identity in all the stocks. The mandril E is supported by three hollow journals F, which revolve in three bearings on the frame of the machine; and the gunstock B is slid inside these journals upon the mandril, and is held in its place by a spring at the muzzle end, shown dotted in Fig. 8, and by two set screws in the other two hollow journals.

There are four revolving cutters C C, Fig. 10, Plate 92, mounted in the four rocking levers D. The bearings of the cutter shaft are carried in a forked swivelling frame G, Fig. 8, inserted in a socket in the top of the rocking lever D, so that the cutter shaft can be set exactly parallel to the axis of the gunstock or slightly inclined to it, according to the shape of the stock; on each prong of the frame G is an adjustable tracer I, Fig. 9, for tracing the form of the pattern cam A. The cam shaft and the mandril E are geared together by a pair of equal spur wheels at each end, and the gunstock is turned round through half a revolution by the hand-wheel H as the shaping proceeds, the cutters being driven by belts J J from the bottom pulleys, Figs. 6 and 7, Plate 89. The cutting blades are screwed to a cast iron block, which is shaped with an undulating surface, as shown in Figs. 8 and 10, so as to present the cutting edges at an angle to the axis of the gunstock and thus ensure a smooth cut across the grain of the wood with somewhat of a paring action.

The portion of the gunstock next to the bands is first shaped by the cutters on one side of the machine, which are brought up by means of the treadle K, Figs. 6 and 7, Plate 89, and the flat steel spring L, Fig. 9. The thin end of the spring L bears against the lower end of the rocking lever D, and presses the tracers I against the pattern cams A. The spring L ensures the tracers keeping in close contact with the cams throughout their revolution, whilst the treadle is kept pressed down by the foot; it also ensures a softer action of the cutters as they are brought up against the wood. A counter spring M on the opposite side of the rocking lever D serves to keep it steady, and to throw off the cutters out of action when the treadle is released. The second pair of cutters on the other side of the machine is then brought up into action in the same manner by the other treadle; and the gunstock being turned round through the remaining half revolution is thus reduced to the finished shape in one revolution of the hand-wheel H.

The other machines of the series are similar in the principles of construction, differing merely in the details of arrangement for performing the special operation intended. By the employment of machinery in this manner, strict accuracy of work is obtained, and all the separate portions of the gun are interchangeable with any gunstock. Although this machinery requires much greater delicacy and accuracy of workmanship and much more careful fitting than ordinary wood working machinery, and is consequently much more expensive, yet the saving in cost of production of gunstocks fully justifies the large outlay incurred in the first cost of the machinery, which is amply repaid by the intricate nature of the operations performed, and the rapidity and exactness with which the work is produced by these machines, as has already been shown to be the case by the success that has attended the government factory at Enfield, where similar machinery is employed for the manufacture of gunstocks.

Mr. Greenwood exhibited the lock bedding machine in complete working order, together with the shaping machine for shaping the gunstock between the bands; and also an entire set of the gunstocks from each stage of the manufacture, showing the condition of the stock after each of the 23 operations, advancing step by step from the original rough wood blank to its final completion in the required form. He explained that of the 23 operations 19 were performed by machinery and 4 by hand, namely Nos. 7, 11, 13, and 17 in the series described in the paper; and these latter it was expected would be reduced shortly to only one hand operation of very small amount.

The Chairman thought the subject of the paper was a very interesting and important one for the gunmakers of Birmingham; and he enquired whether any of the machines described were at work there for the manufacture of gunstocks.

Mr. Greenwood replied that there were not any of the machines at work yet in Birmingham, but a complete set of them was in operation at Enfield, where they had been in use for several years; and also a nearly similar set at the London Armoury Company's works in London. The machines now exhibited were constructed for making only one length of gunstock, and some modifications had therefore been introduced for simplifying the construction and mode of driving; but the machines in use at Enfield would take in three different lengths of gunstocks, namely carbines, short Enfields, and ordinary long Enfields, the last of which formed the greater proportion of the guns manufactured. At Enfield with two sets of the machines 2000 gunstocks per week on the average were produced; but at that rate of work the machines were not fully employed, and in full work one set of machinery would produce 1200 gunstocks per week. At present the gunmakers of Birmingham had to pay a high price to have their gunstocks made by machinery in London, in order to secure greater accuracy and finish of workmanship than was obtained in hand work.

The Chairman remarked that the machine work certainly appeared much superior in quality to that done by hand. He enquired whether the lock bedding process performed by the machine now exhibited was reckoned as five separate processes in the series of operations for making a gunstock.

Mr. Greenwood replied that there were 19 separate machines in the complete set, and the lock bedding was counted as only one operation, though divided into five parts for convenience and accuracy of work, as had been described, since it was necessary to be very particular in ensuring perfect accuracy in every part of the work.

The Chairman enquired where the original machines for the manufacture of gunstocks had been used, from which the machinery now described had been derived.

Mr. Greenwood said the gunstock machinery was of American origin, and the American government had been occupied for the last twenty years in perfecting the manufacture of guns by machinery at the armouries of Springfield and Harper's Ferry. At the time of the Crimean war Mr. John Anderson, Col. Burn, and Lieut. Warlow were sent over from England as a commission to investigate the manufacture of arms in the United States, and an arrangement was made with the Ames Company to supply two or three sets of machines to this country, the American government consenting to furnish all the information in their power on the subject. The first attempts however at the use of machinery proved fruitless, as several of the machines first made failed and had to be abandoned; but the work was resumed, and resulted in the machinery now in use in the Enfield factory. The original machinery was intended to turn out 500 gunstocks per week, and had since then been supplemented by further machinery from America and also from his own works, so as to produce now 2000 gunstocks per week. The machines supplied from his own works had been constructed for the purpose of making different lengths of Enfield gunstocks in the same machines, so as to prevent the necessity of having different sets of machines for different sizes of gunstocks. Two or three other sets of machinery were also made subsequently by the Ames Company, but none had been got successfully to work except that supplied to the London Armoury Company; and the Russian government purchased a set through Col. Colt, which had also not been brought into actual operation at present. The machinery at Enfield was at first worked under the superintendence of men sent over from America; but more guns were now being turned out there than at that time, and the machines were working very successfully, producing very smooth and accurate work.

The Chairman thought the construction of the machines must be rendered considerably more complicated if it were attempted to make different sizes of gunstocks in the same machines, instead of employing a second set of machinery for a different size of stock.

Mr. Greenwood observed that the shape of the work could be changed to a considerable extent in the same machine by simply changing the pattern that was being copied, and having the cutting tools so shaped that they would follow any pattern required. One essential condition of success was that the cutters should be adjusted with extreme accuracy and maintained with a very sharp cutting edge; and they were driven at a high speed, making from 5000 to 6000 revolutions per minute in the lock bedding machine, and about 2000 revolutions per minute in the shaping machine.

The Chairman enquired what was the cost of a complete set of the gunstock machinery; and how the gunstock was adjusted with the required accuracy to its proper position in the several machines, so that each machine should follow and take up the work correctly from the preceding one.

Mr. Greenwood said the cost of a set of the machines complete with all accessories would be about £8000 for producing 500 gunstocks per week. The machines were all arranged in a row, so that the work was passed on from one to another successively throughout the entire series; and one considerable difficulty that had been met with was to get some simple and efficient means of readily fixing the gunstock in its proper position in each machine, so as to ensure exact correspondence in the shaping of all the stocks. The first four operations consisted simply in reducing the original wood blank roughly to the shape of the stock, and no accuracy of adjustment was needed in them; but in the fifth operation, termed "spotting," the accuracy commenced, the "spots" or flat places cut on each side of the stock in this operation being portions of one plane and forming the basis of adjustment for the sixth operation, in which the groove was cut for the barrel, the stock being fixed in the proper position in the machine by means of the "spots" previously cut on it. The barrel groove then became the basis for all the subsequent operations, each machine having a mandril exactly corresponding with the

gunbarrel, upon which the stock was readily slid endways, and pushed home to the squared end of the groove, and then fixed in its place.

The CHAIRMAN enquired what amount of wear there was upon the principal bearings of the lock bedding machine, and how they were kept in repair.

Mr. GREENWOOD replied that there would be no difficulty in keeping the bearings completely in order, as all the bushes were of hardened steel, and the work was fitted with such accuracy that the circular cage and the drill slides were moved easily by a light touch. The drill spindles had a conical neck at the bottom end, running in a conical steel bush hung on centres, and the top end of the spindle ran in a parallel bush, with a loose collar that took the end thrust of the drill, so that the spindle was kept perfectly free and ran very smooth and steady, without any strain under the high speed at which it was driven; a lock nut at the upper end gave the means of taking up the wear of the conical bearing at bottom and the collar at top. The small driving friction rollers at the top of the drill spindles were made of ebonite, vulcanised india-rubber with an extra quantity of sulphur in it, which was a very hard and durable material, well adapted for the purpose.

Mr. F. J. BRAMWELL asked whether that mode of driving the drill, by means of a friction roller driven by contact with the central driving drum, did not make the drill slide less easy to move laterally: he remembered in the machines made by the Ames Company a separate strap with fast and loose pulleys to each drill spindle was used in similar cases, that the movement of the drill slide might not be hindered by the friction.

Mr. GREENWOOD said the tendency of the driving drum to carry the drill slide round with it did not produce any difficulty in working the machine, and the drill slide was moved in either direction by the handle with the greatest ease and lightness; and when the handle was let go the slide was raised by the spring behind, and the friction roller thereby lifted out of contact with the driving drum. With a separate strap to each drill there was the objection that each strap had to be thrown in and out of gear successively; and the plan now adopted had therefore the advantage of greater simplicity and facility of working.

Mr. F. J. Bramwell observed that the advantage in machine work was very great in the facility and rapidity of fitting the work together, on account of all the parts being strictly accurate as duplicates; and the price and time of putting a gun together complete would give the best idea of the perfect uniformity and finish with which the several portions of the work were produced by the machinery. He understood that the cost of putting together at Enfield was now reduced to only $1\frac{1}{4}d.$ each, since all the parts were exact duplicates of one another, in consequence of being made by machinery. He enquired what was the time occupied in putting each gun together complete, when made by machinery.

Mr. Greenwood replied that the time required for putting together a gun was now only six minutes, including the ramrod, bayonet, and oiling over the stock. The lock was finished and put together beforehand ready for the workman, and the screw holes being ready drilled in the stock all he had to do was to put it into the recess in the stock and screw it in. All the other parts of the gun furniture were taken up promiscuously from a lot of each sort, and put into the stock, and the only tool used by the workman was a hand brace with a screwdriver in it.

Mr. J. Fernie observed that he had been much interested in seeing the machinery at Enfield, and thought the lock bedding machine now exhibited was a very beautiful specimen of machinery and a decided improvement upon the machine used there, as it had no loose straps in connexion with the several drills, in consequence of the drills being driven by friction rollers by the central driving drum, and it was altogether a better arranged machine. The mode of compensating for the wear of the drills, by fixing each drill with an eccentric shank in an eccentric socket in the drill spindle, was also an ingenious contrivance, affording the means of maintaining constantly the correct size of the cutter and ensuring perfect accuracy of work, by turning the drill round a little in the socket when its diameter had become reduced by sharpening. A shaping machine similar in principle to that exhibited for shaping the outside of the stock had been employed for some time at Derby for shaping wood spokes for carriage wheels, by means of revolving cutters copying from a pattern.

He enquired what sort of copying lathe was used for turning the butt end of the stock, and how the polishing of the stock was done to finish it ready for use.

Mr. Greenwood replied that the stock was merely rubbed with sand paper to remove the slight roughness of the surface left by the grooving action of the cutters; and it was then polished by hand in the ordinary manner. The lathe for turning the butt end of the stock was one of the ordinary Blanchard copying lathes, the invention of which, though generally supposed to belong to America, really belonged to South Staffordshire, the lathe having he believed been originally invented by a gentleman named Rigg, living not far from Birmingham, for the purpose of turning shoe lasts; the invention was afterwards taken out to America, whence it returned again to this country under its present name of the Blanchard lathe, and was now employed very extensively in large numbers of manufactures.

Mr. F. J. Bramwell remembered having seen a lathe with a revolving cutter mounted on an oscillating frame in the Adelaide Gallery in London about 25 years ago, which copied from a complete iron pattern of the required shape, and was capable of undercutting to a certain extent; and the same principle had been applied in Jordan's wood carving machine. In ordinary wood-working machines however the work produced was not required to fit together: but in the gunstock machinery now described absolute truth of workmanship was necessary, so that the several parts of the gun might fit in the stock with perfect accuracy.

The Chairman moved a vote of thanks to Mr. Greenwood, which was passed, for his paper and for the machines and the complete set of specimens of the gunstocks that he had exhibited.

The following paper was then read:—

DESCRIPTION OF A HYDRAULIC SHEARS AND PUNCH.

By Mr. JAMES TANGYE, of Birmingham.

The object of this Hydraulic Shears is to afford the means of readily cutting large sections of bar iron or railway rails, with the power of one man only, and with a machine of simple and compact construction.

This shears is shown in Figs. 1 and 2, Plate 93, and consists of a strong vertical cast iron frame A A, divided in the centre horizontally, in the upper half of which the upper shear blade B is fixed; and a short hydraulic press C is cast in the lower half of the frame, having the lower shear blade D fixed upon the top of the ram of the press, which is 10 inches diameter with 3 inches length of stroke. The upper and lower castings of the frame are secured together by two bolts E E, 3 inches diameter. The box F bolted upon the side of the cylinder contains the force pump G, and serves as the reservoir for the water of the pump. The pump is worked by the lever H, and consists of a single brass casting, shown enlarged to half full size in Fig. 5, Plate 94. This pump is screwed into its place in the side of the hydraulic press C, and contains a small conical suction valve I and delivery valve K, ½ inch diameter, held down to their seats by spiral springs. A small wire gauze guard is fixed over the outside of the inlet and outlet openings of the pump, to prevent any dirt from getting into the press cylinder. The plunger L, ⅝ inch diameter and 1⅛ inch stroke, is continued backwards to work in a guide socket in the end of the reservoir F, and a tongue M on the shaft of the hand lever H works in a square slot in the plunger rod.

The shear blade D, Figs. 1 and 2, Plate 93, is lowered after the cut by means of a self-acting motion connected with the force pump lever. The length of stroke of the lever is limited in ordinary

working by a stop pin fixed on the side of the cistern, which catches the lever at the bottom of its stroke; but by shifting the lever ⅜ inch outwards upon the squared end of the shaft, it is made to clear this stop pin, and is pushed down into a lower position. The tongue working the plunger then advances to the position M, Fig. 5, Plate 94, its ordinary working limits being the two dotted positions O O. The prolonged end of the plunger then reaches the delivery valve K of the pump and presses it open, allowing the water to flow back from the press cylinder into the pump; and at the same time the water is allowed to flow through the centre of the plunger by a hole drilled through the entire length of the plunger. This hole is closed at the outer end by a conical escape valve P opening outwards, which is kept shut in ordinary working by the tongue M of the hand lever; but when the lever is depressed below the stop for lowering the shears, a recess in the tongue is brought over the head of the escape valve P, allowing the valve to be forced back from its seat by the water pressure, and leaving a passage open for the water to escape through the hole in the plunger back into the cistern. The act of raising the hand lever again into its working position closes the escape valve P and keeps it shut during the working of the pump. A second force pump of larger size, with 2 inches diameter of ram, is used to bring up the shears quickly to the work to be cut.

With this shears a bar of wrought iron 3 inches square is readily cut by one man, the time required being about 2¼ minutes. Different sizes of the shears are made for cutting bars up to 3½ inches square; the smaller sizes of bars being cut off several at a time.

This hydraulic shears is found very useful in iron warehouses for cutting large bars, where the power of only one or two men is available; and also on railways for cutting the rails, for which purpose the shears can be readily carried on an ordinary platelayer's lorry, no other foundation being required, and the whole weight being only 14 cwts. In the case of cutting rails, the shear blades are made of the same shape as the outline of the two sides of the rail, as shown in Figs. 1 and 2, Plate 93, so as to cut the whole section at once and make a clean square cut.

The Hydraulic Punch, shown in Figs. 3 and 4, Plate 94, is of similar construction to the shears already described, only inverted in arrangement, having the fixed die A at the bottom, and the punch B fixed on the end of the inverted ram C of the hydraulic press, which is 6 inches diameter with 2 inches length of stroke. The box F containing the force pump G and reservoir of water is fixed on the side of the press cylinder at the top. The punch is withdrawn quickly after the stroke by means of the spiral spring E pulling up the ram; the water being allowed to escape back from the press cylinder to the cistern through the centre of the plunger by the same means as in the shears already described.

With this punch a hole 1 inch diameter is punched in a ⅞ inch iron plate, with the power of one man in about half a minute. The machine is very portable, the total weight being only 4½ cwts.; and it has been applied with advantage to punching the holes for fish bolts in railway rails, as shown in Figs. 3 and 4, Plate 94. A successful application of this machine has also been made to the manufacture of horse shoes, by punching them out cold, with the holes and countersink complete at one operation.

The Hydraulic Lifting Jack, shown in Figs. 6, 7, and 8, Plate 95, is constructed on the same plan as the shears and punch before described, as regards the force pump G, shown enlarged to half full size in Fig. 9. The jack consists of an inverted hydraulic press A, the ram of which C forms the foot upon which the jack stands, and the pump G and reservoir of water F are fixed on the opposite end of the press cylinder, and form the head of the jack. The ram C is of wrought iron, 3½ inches diameter and 12 inches length of stroke, with the foot forged upon it; and the press cylinder A is formed of a hammered wrought iron bar, bored out of the solid, leaving ⅝ inch thickness of metal for the sides of the cylinder. A claw B is forged on one side of the cylinder at the bottom, for the purpose of using the jack to lift from the bottom when required. The head F forming the reservoir of water is of malleable cast iron, fixed upon the top end of the cylinder by being bored out a tight fit and pressed on up to a shoulder.

The jack is lowered by similar means to that previously described for the shears and punch; except that instead of the water escaping through the plunger L, Fig. 9, Plate 95, the suction valve I is forced open by the same movement that presses open the delivery valve K by means of a small inclined plane upon the prolonged end of the plunger L, which passes through an eye in the stalk of the suction valve I, and draws back the valve from its seat directly after the delivery valve K has been pressed open, allowing the water to flow back into the reservoir in the contrary direction to the ordinary working.

The ram of the jack is packed with a cupped leather D, shown black in Fig. 6, Plate 95, resting in a hollow $\frac{3}{16}$ inch deep turned in the top of the ram. These leathers have been found thoroughly successful in standing the pressure and wear, the same leathers having been in regular work for several years without requiring renewal. The force pump plunger L in the lifting jack and also in the shears and punch is packed with a narrow strip of leather $\frac{3}{16}$ inch wide, coiled round spirally in a groove turned near the bottom of the plunger, as shown in Figs. 5 and 9, with the ends of the strip bevilled off to fill up the groove close.

The hydraulic jack shown in Plate 95 is for lifting 30 tons, and several different sizes are made for weights from 4 to 60 tons. The head of the jack is prevented from turning round by a sliding block working in a longitudinal groove E in the ram; but by withdrawing the screw that fixes the block the head is allowed to turn freely with the load upon it. The hydraulic jack is convenient for use with heavy weights, from the great power obtained, one man being able to lift readily 30 tons and upwards; and from the lightness of construction, the 30 ton jack weighing only about $1\frac{1}{2}$ cwts. At the same time the loss of power from friction is comparatively small; and the small extent of wear to which the working parts are subjected gives great durability and freedom from risk of derangement.

Mr. Tangye exhibited a specimen of the hydraulic lifting jack and of the force pump used in the hydraulic shears and punch, together with specimens of bars and rails sheared and punched by them. He explained that the shearing machine was a modification of the hydraulic shearing press described at a former meeting of the Institution in 1858, the present shears and punch being made much smaller and lighter, so as to be easily portable and to give the means of readily shearing or punching bars or rails by the power of one man.

The Chairman enquired whether any of the hydraulic shears were in use on railways for cutting rails.

Mr. Tangye replied that two or three hydraulic shears were at work on railways for that purpose, the first having been applied about two years ago; and some were employed in iron warehouses for cutting the bars of iron, one having been in use now for five years.

Mr. G. M. Miller thought the shears would be a useful and convenient machine for use on a railway, particularly on curves where the joints of the inner rail overtook those of the outer, so that every third or fourth rail on the inner side had to be cut shorter, in order to bring the joints opposite each other and keep the sleepers square across the line; but he thought it would be desirable to get a smoother cut than was shown in the rails exhibited. He enquired whether the rails were sheared cold, and how the cutters were found to stand the work.

Mr. Tangye said the rails were sheared cold, and the cutters stood well when of proper quality of steel. Several thousands of cuts had been made with the machine first constructed, without the cutters requiring renewal yet; and a machine of the size shown in the drawings was strong enough for cutting bars of iron 3 inches square. The sheared rails exhibited were not favourable specimens of the cut made by the machine, the cutters not having been good in this case; but the machine generally sheared tolerably smooth, leaving the ends of the rails quite ready to go together without any labour of dressing them off for the purpose.

The Chairman asked whether the hydraulic lifting jack had been in use for any length of time.

Mr. Tangye replied that in its present form, with the force pump and reservoir of water contained inside the head of the jack, it had been in use about eight months; but a previous make, similar in construction but having the pump outside the jack, had been in use for five years. About 200 of the jacks had already been made of various sizes.

Mr. D. Joy observed that some delicacy of adjustment appeared to be necessary in the stud at the bottom of the force pump plunger, if it were required to open both the valves simultaneously for lowering the jack; and he enquired whether those parts of the pump had proved durable in working.

Mr. Tangye explained that the two valves were not required to be opened at the same instant, but it was only necessary to ensure that the lower or delivery valve was opened by the stud before the suction valve. The valves and working parts, though small in size, were made very durable: their durability had been severely tested by three days' constant work, raising and lowering a weight of 3 tons three or four times in a minute continuously, which gave the jack as much work as it was likely to have to do in twelve months; and at the end of the trial all the working parts were found in as good condition as at first.

The Chairman enquired what was the weight of the small sized jack exhibited, and what load it would lift.

Mr. Tangye said the small jack exhibited weighed 60 lbs. and was intended for lifting 4 tons load; the jack shown in the drawings weighed 150 lbs. and would lift 30 tons.

Mr. G. M. Miller asked whether the reservoir ever wanted filling with water again, and what means there was of replenishing it.

Mr. Tangye said that sometimes a little leakage took place if the cupped leather had been allowed to get dry by the jack standing unused for a length of time without a full supply of water; but after the leather had been soaked for a few minutes it became quite water-tight again. The reservoir was easily filled at any time through a plug hole in the jack head, or by turning the jack upside down and drawing out the ram; and when the jack was kept fully charged with water, the leather was always moist and in working order. There was

no difficulty in keeping the jacks always full of water, and they were usually supplied ready filled with water; but some jacks sent to St. Petersburg had been sent empty, to prevent any risk of the water freezing and bursting them.

Mr. G. M. Miller enquired whether the jacks were ever worked with oil instead of water, and whether the water had to be let out of the jacks in frosty weather in this country.

Mr. Tangye said the jacks were usually worked with water made soft with soap and oil; sometimes in winter they were filled with oil, to avoid risk of freezing in the most severe weather, but he had not heard of any instance of a jack being burst by the frost.

The Chairman proposed a vote of thanks to Mr. Tangye for his paper, which was passed.

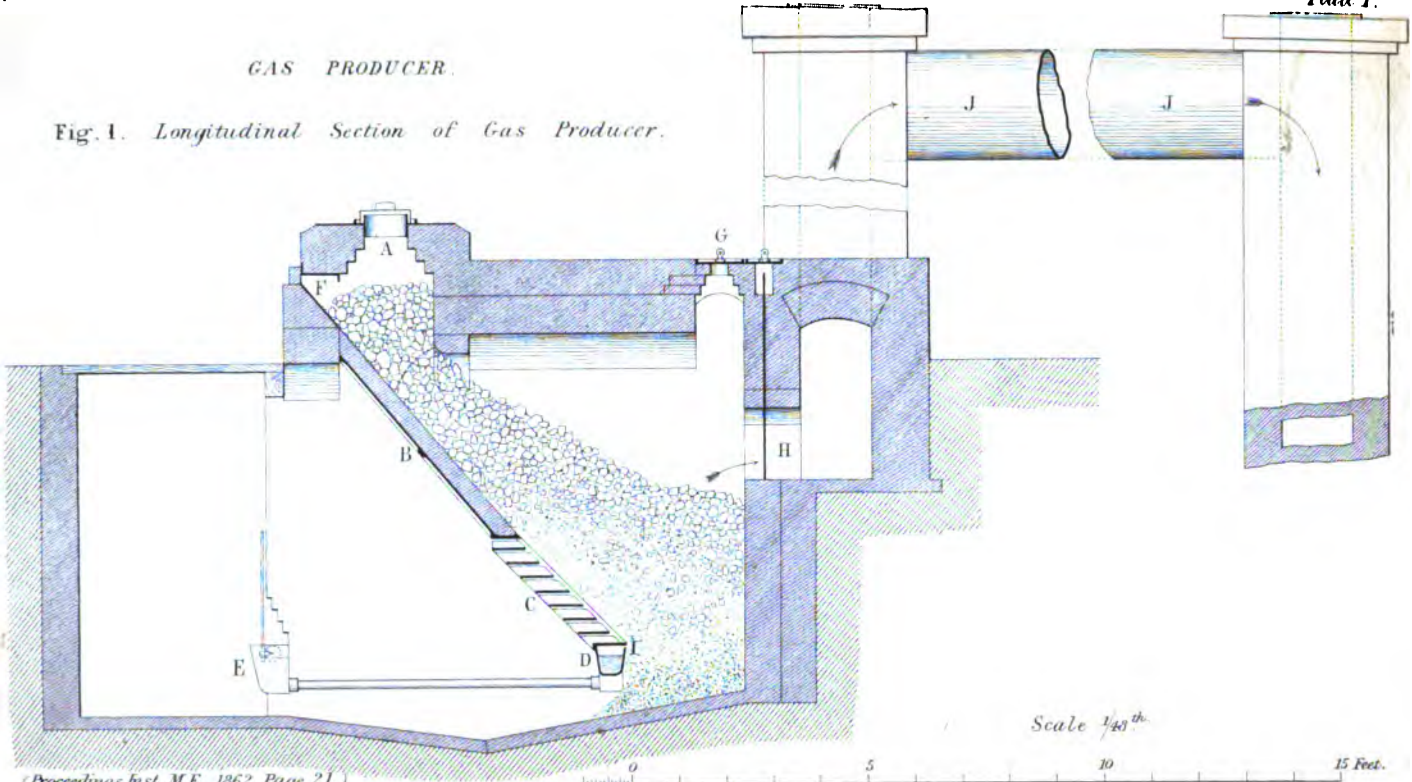
The Meeting then terminated.

REGENERATIVE GAS FURNACE.

Plate 1.

GAS PRODUCER.

Fig. 1. *Longitudinal Section of Gas Producer.*



REGENERATIVE GAS FURNACE. Plate 2.

GAS PRODUCER.

Fig. 2. Front Elevation and Transverse Section at front.

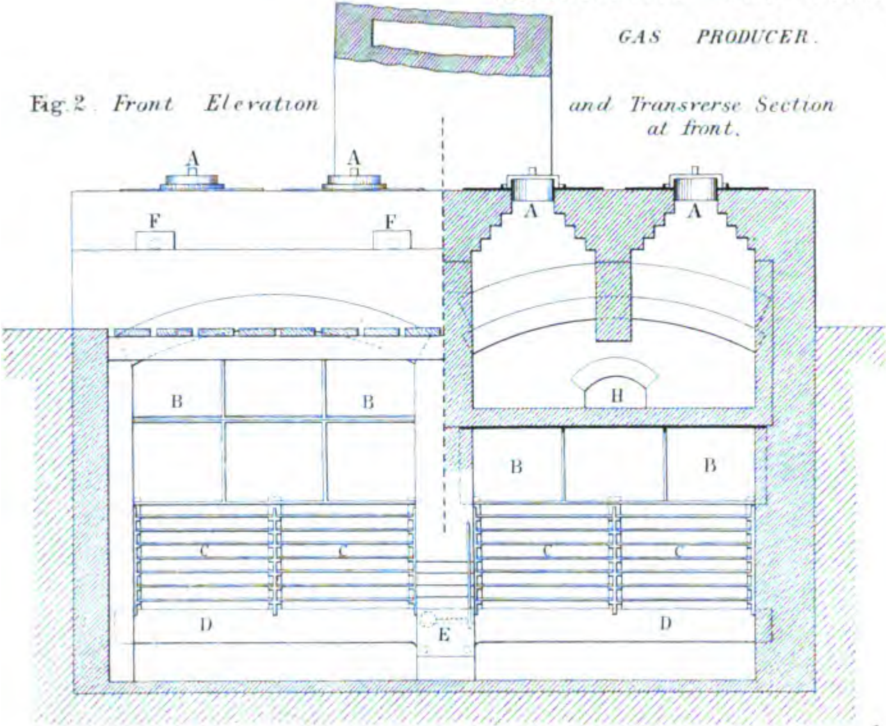
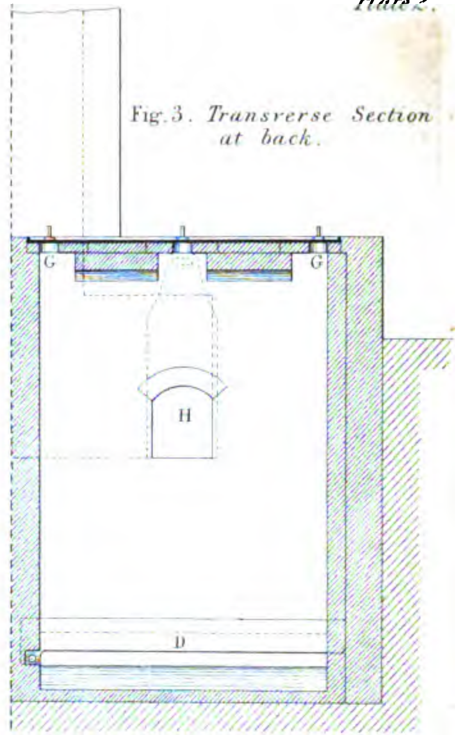


Fig. 3. Transverse Section at back.



Scale 1/48th

0 5 10 15 Feet

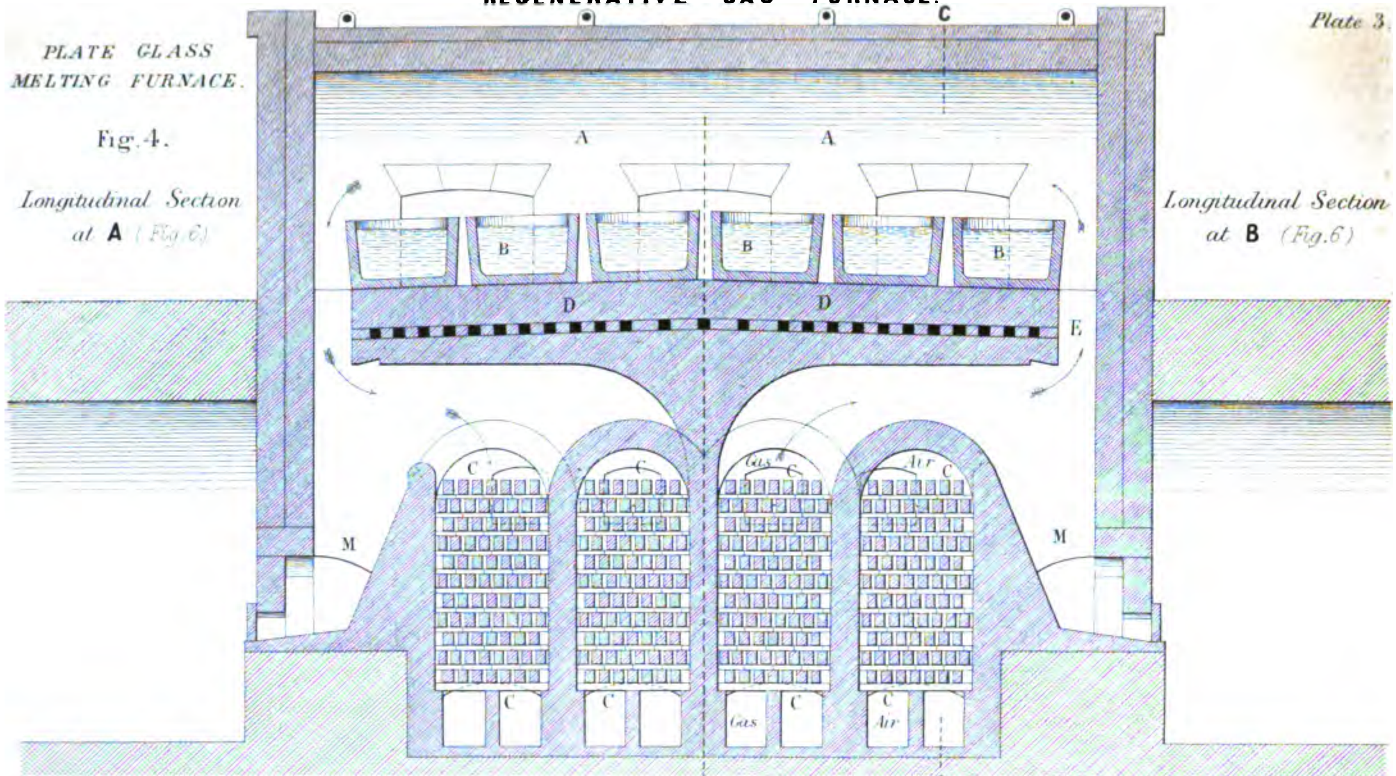
REGENERATIVE GAS FURNACE.

PLATE GLASS MELTING FURNACE.

Fig. 4.

Longitudinal Section at A (Fig. 6)

Longitudinal Section at B (Fig. 6)



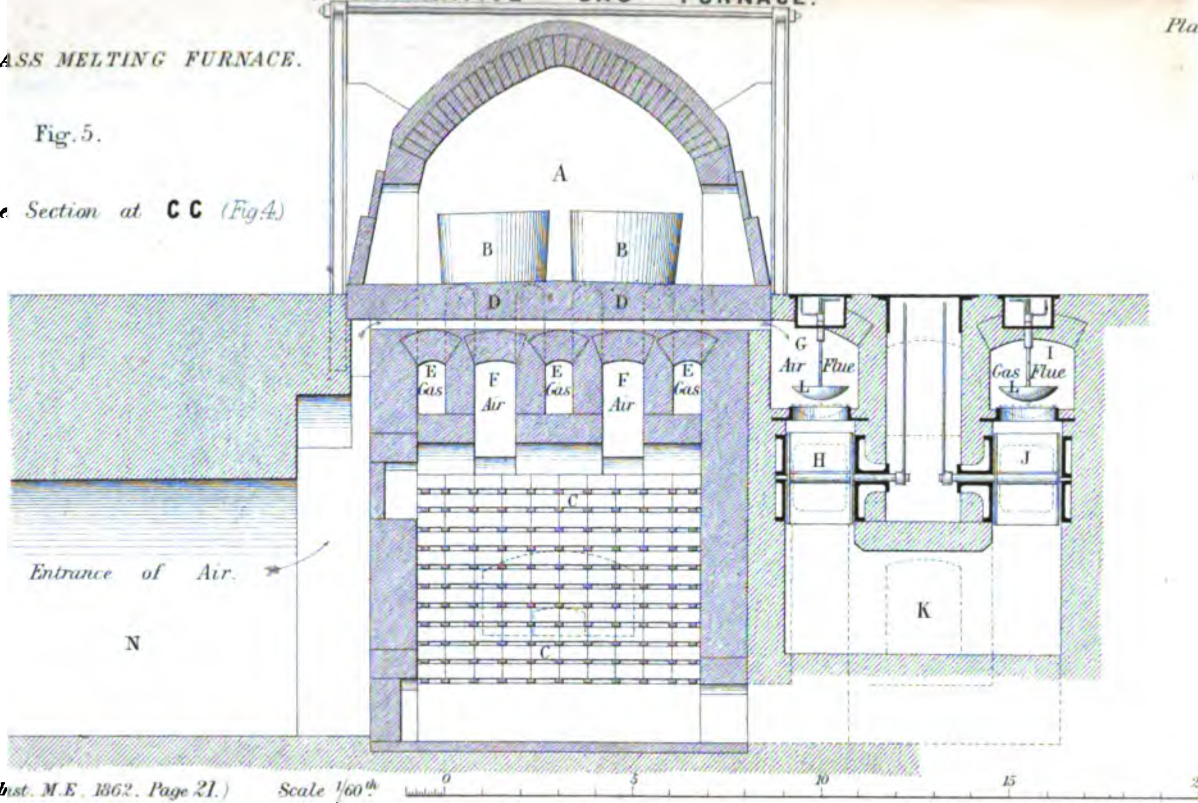
REGENERATIVE GAS FURNACE.

Plate 4.

PLATE GLASS MELTING FURNACE.

Fig. 5.

Transverse Section at C C (Fig 4)



(Proceedings Inst. M.E. 1862. Page 21.)

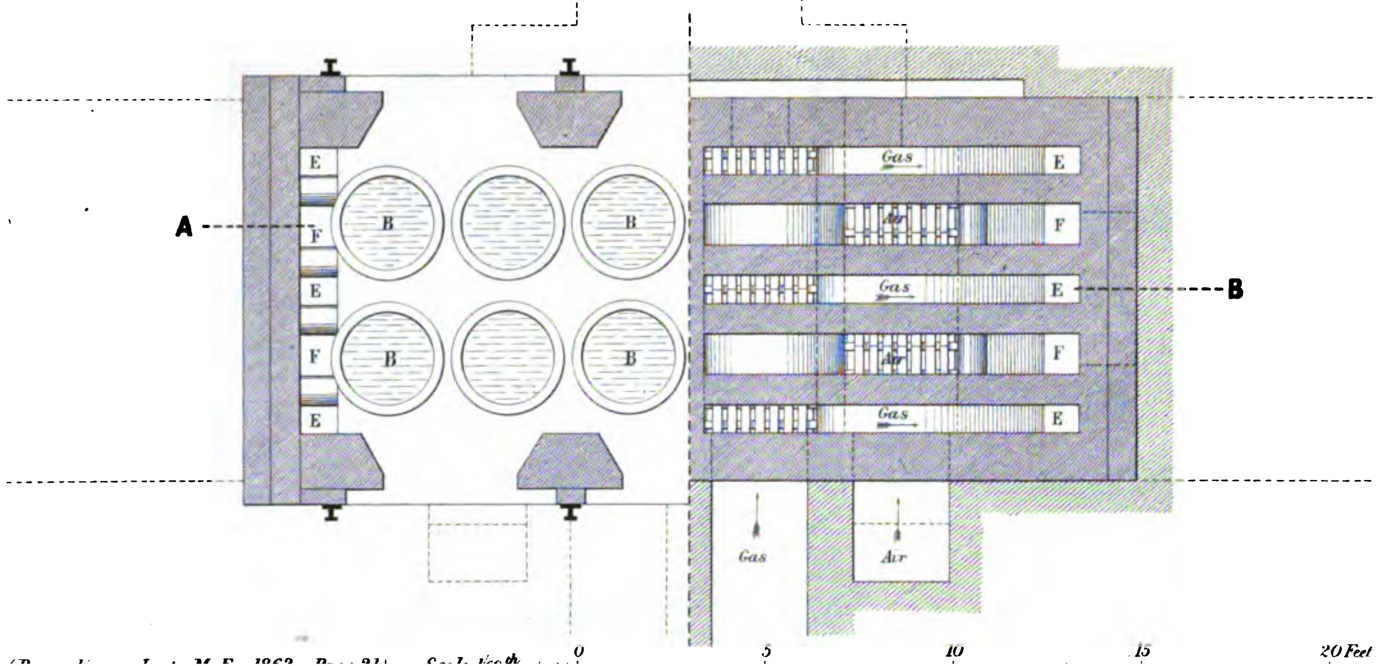
Scale 1/60th

REGENERATIVE GAS FURNACE.

PLATE GLASS MELTING FURNACE.

Fig. 6.

Sectional Plan above siege. Sectional Plan below siege.



REGENERATIVE GAS FURNACE. Plate 6.

PLATE GLASS MELTING FURNACE.

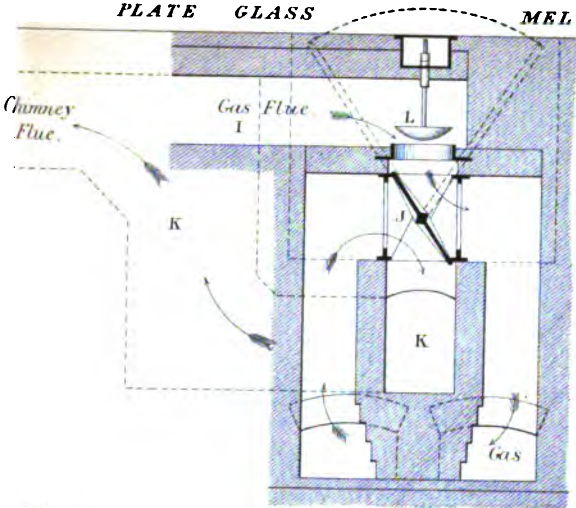
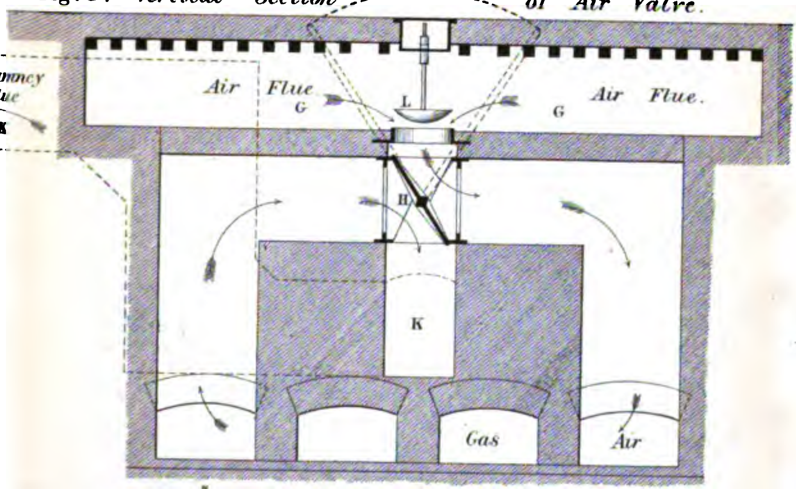


Fig. 7. Vertical Section of Gas Valve.

Fig. 8. Vertical Section of Air Valve.



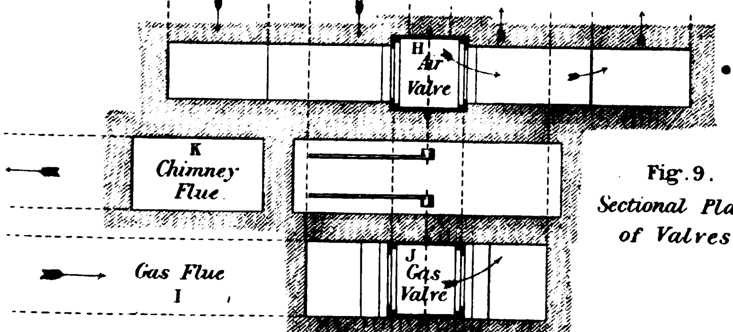


Fig. 9. Sectional Plan of Valves.

(Proceedings Inst. M. E. 1862. Page 21)

Scale 1/60th
0 5 10 15 Feet.

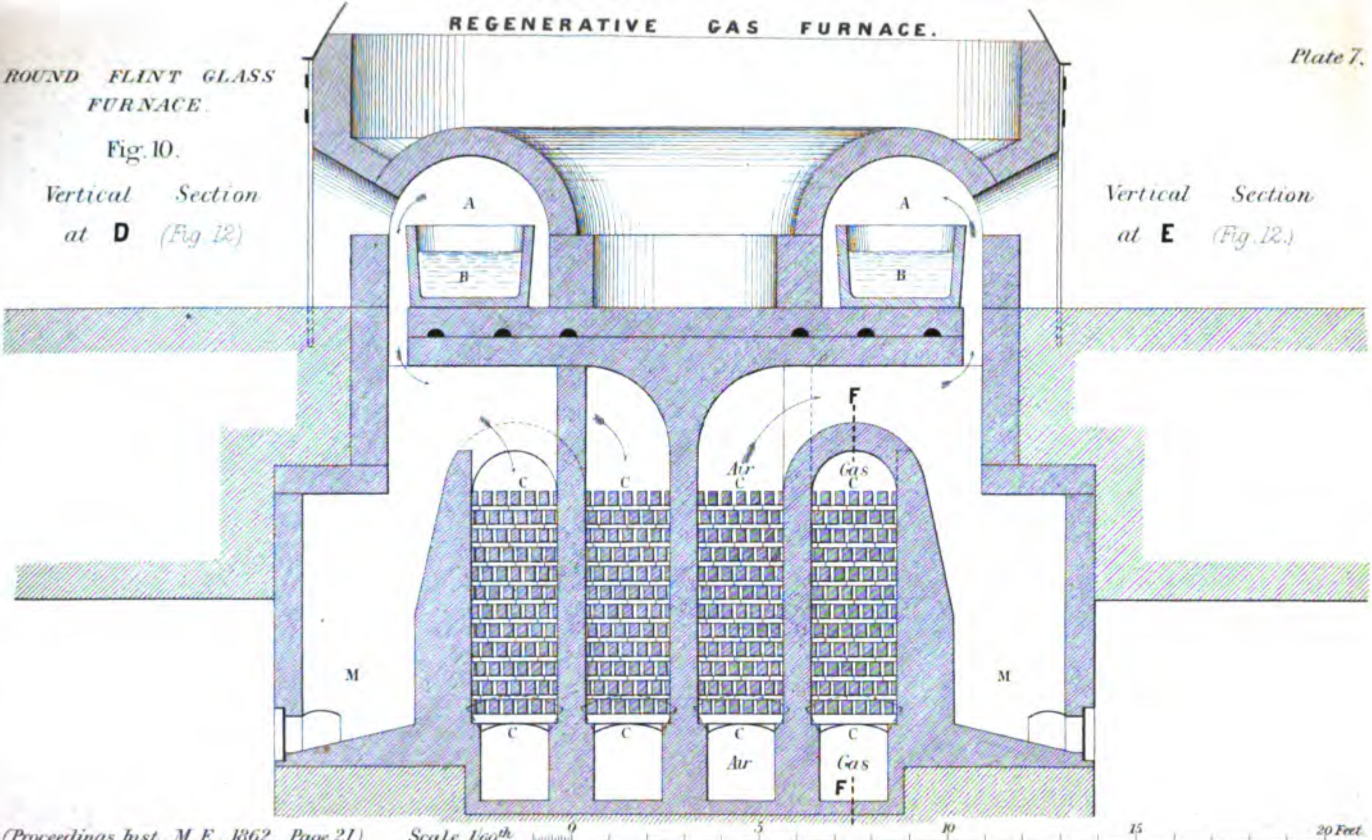
REGENERATIVE GAS FURNACE.

ROUND FLINT GLASS FURNACE.

Fig. 10.

Vertical Section at **D** (Fig. 12)

Vertical Section at **E** (Fig. 12.)



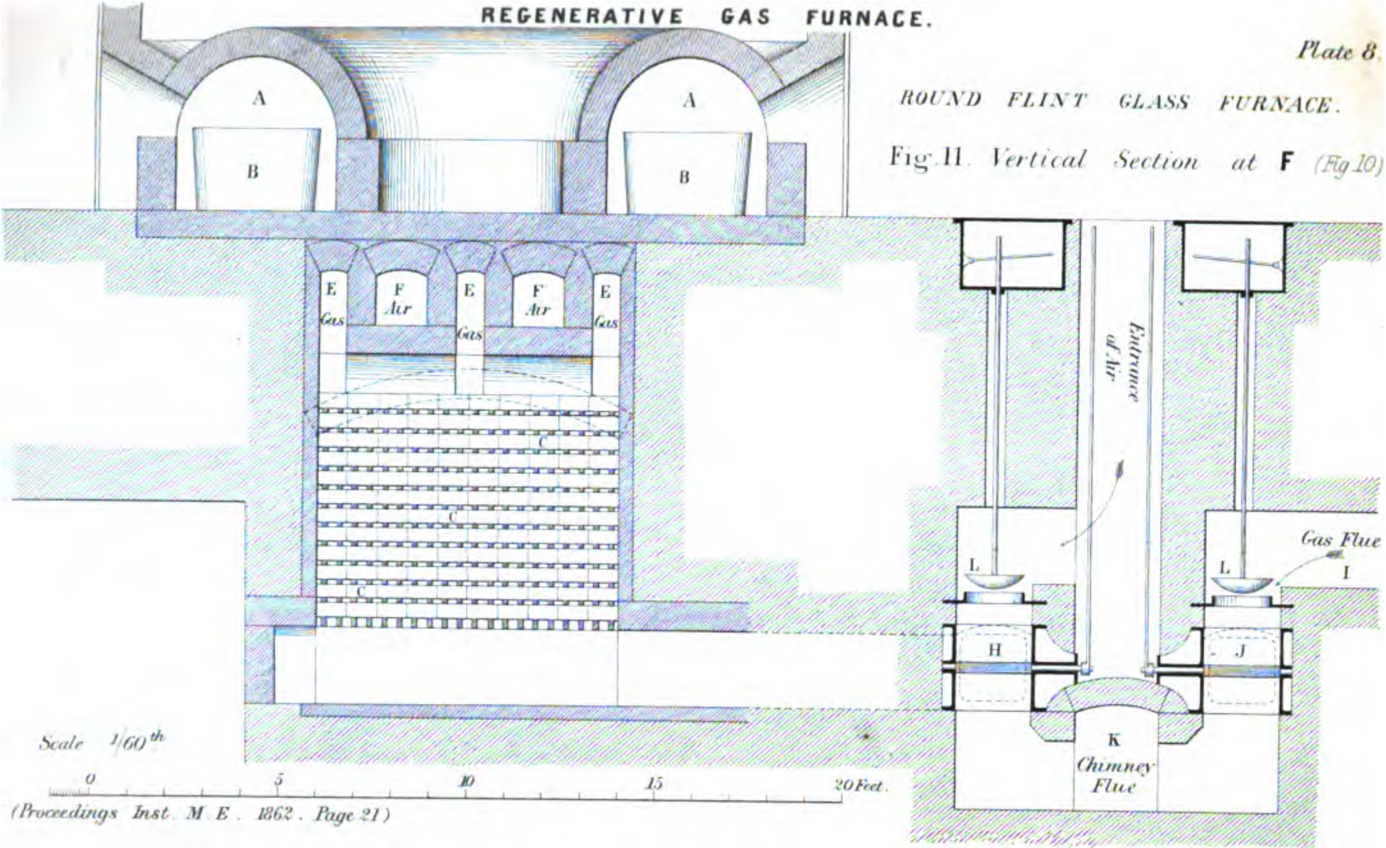
Scale 1/60th

Plate 8.

REGENERATIVE GAS FURNACE.

ROUND FLINT GLASS FURNACE.

Fig. 11. Vertical Section at **F** (Fig. 10)



(Proceedings Inst. M. E. 1862. Page 21)

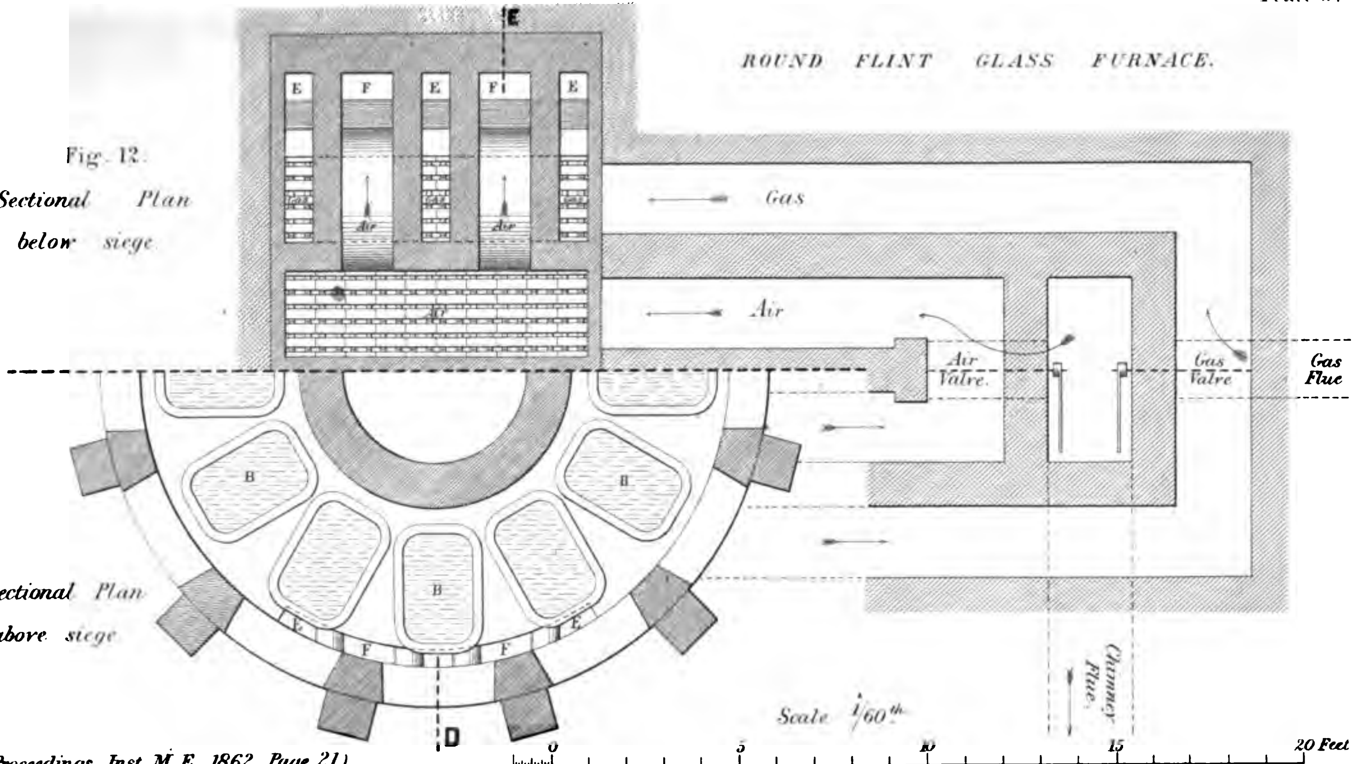
REGENERATIVE GAS FURNACE.

ROUND FLINT GLASS FURNACE.

Fig. 12.

Sectional Plan below siege

Sectional Plan above siege



REGENERATIVE GAS FURNACE. *Plate 10.*

PUDDLING FURNACE.

Fig. 13. *Longitudinal Section.*

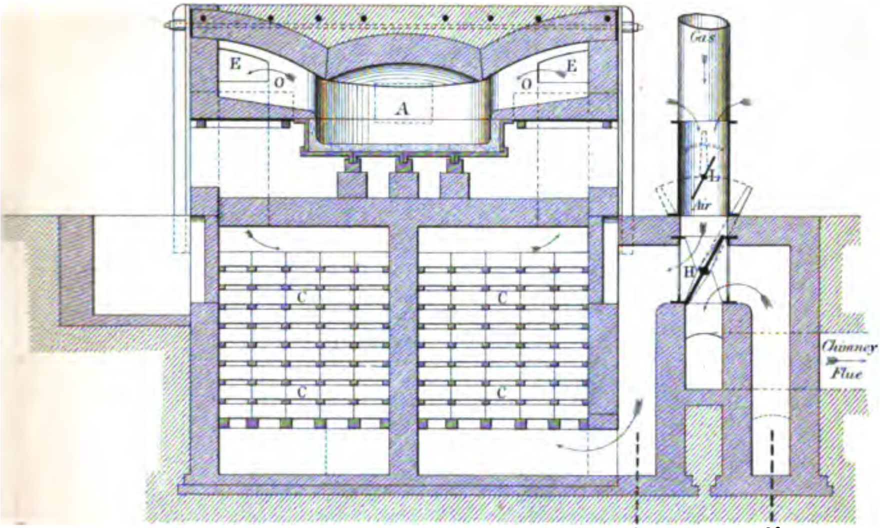


Fig. 14. *Sectional Plan of Puddling Chamber.*

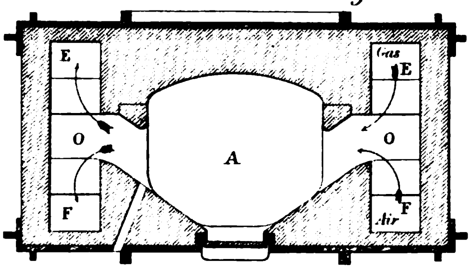
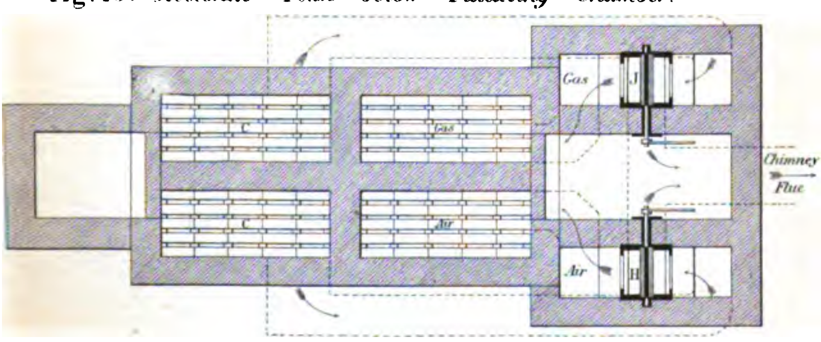


Fig. 15. *Sectional Plan below Puddling Chamber.*



(Proceedings Inst. M. E. 1862. Page 21) *Scale 1/60th*

0 5 10 15 20 Feet.

REGENERATIVE GAS FURNACE. *Plate 11.*

PUDDLING FURNACE.

Fig. 16. Transverse Section through mixing chamber O.

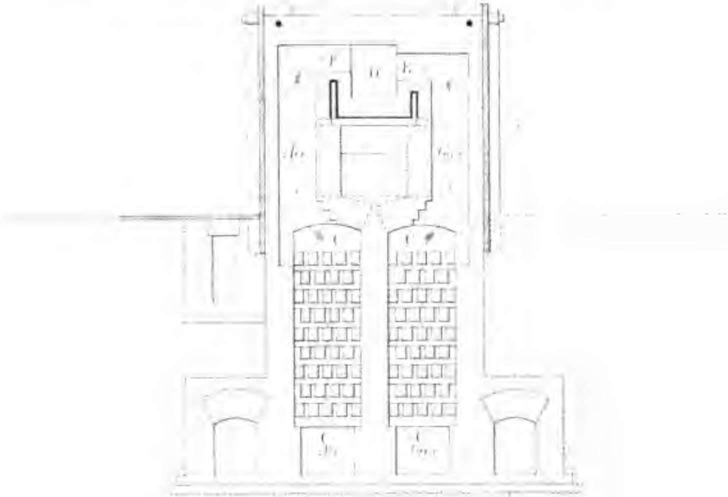


Fig. 17.
Vertical Section at **G**

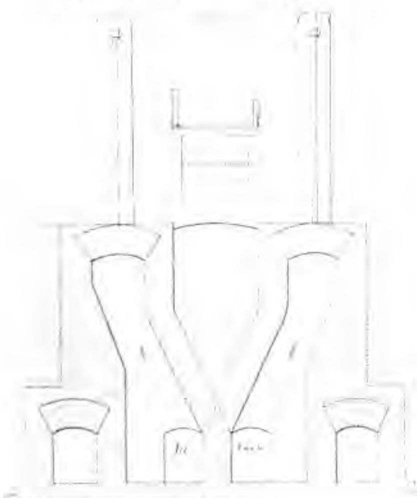
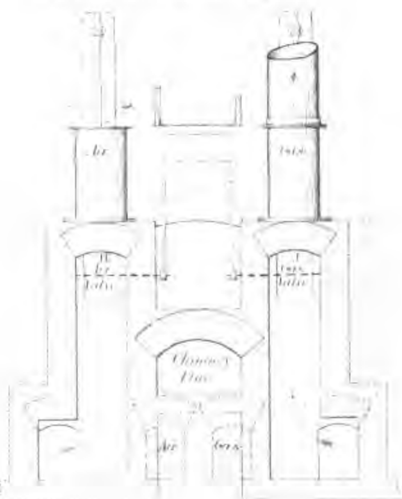


Fig. 18.
Vertical Section at **H**



Scale 1/48th

0 10 20 Feet

Plate 12.

REGENERATIVE GAS FURNACE.

STEEL MELTING FURNACE.

Fig. 19. Longitudinal Section.

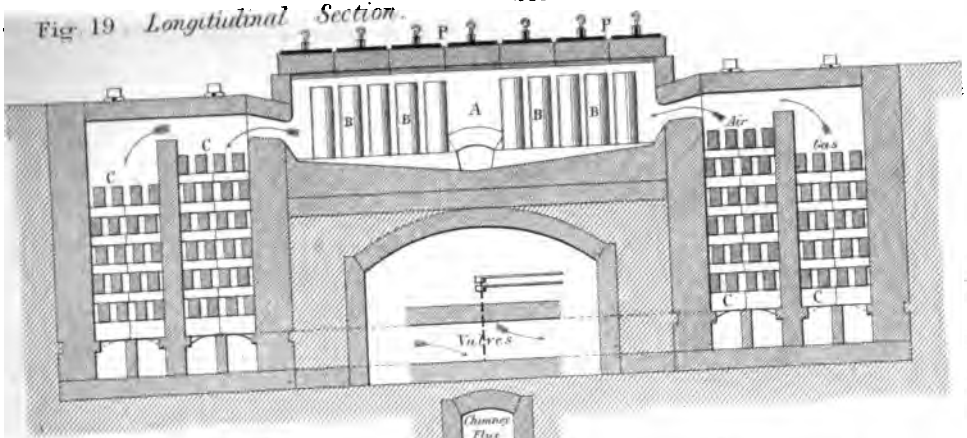


Fig. 20. Transverse Section.

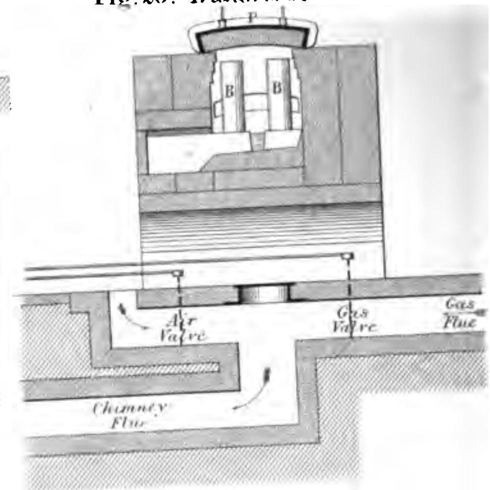
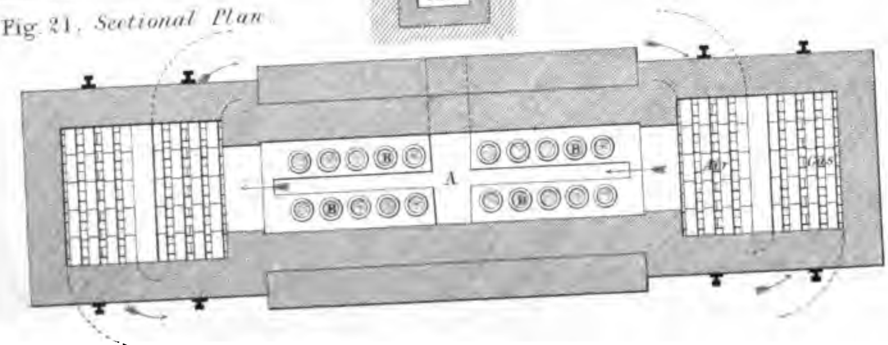
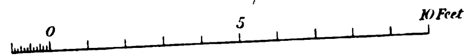


Fig. 21. Sectional Plan.



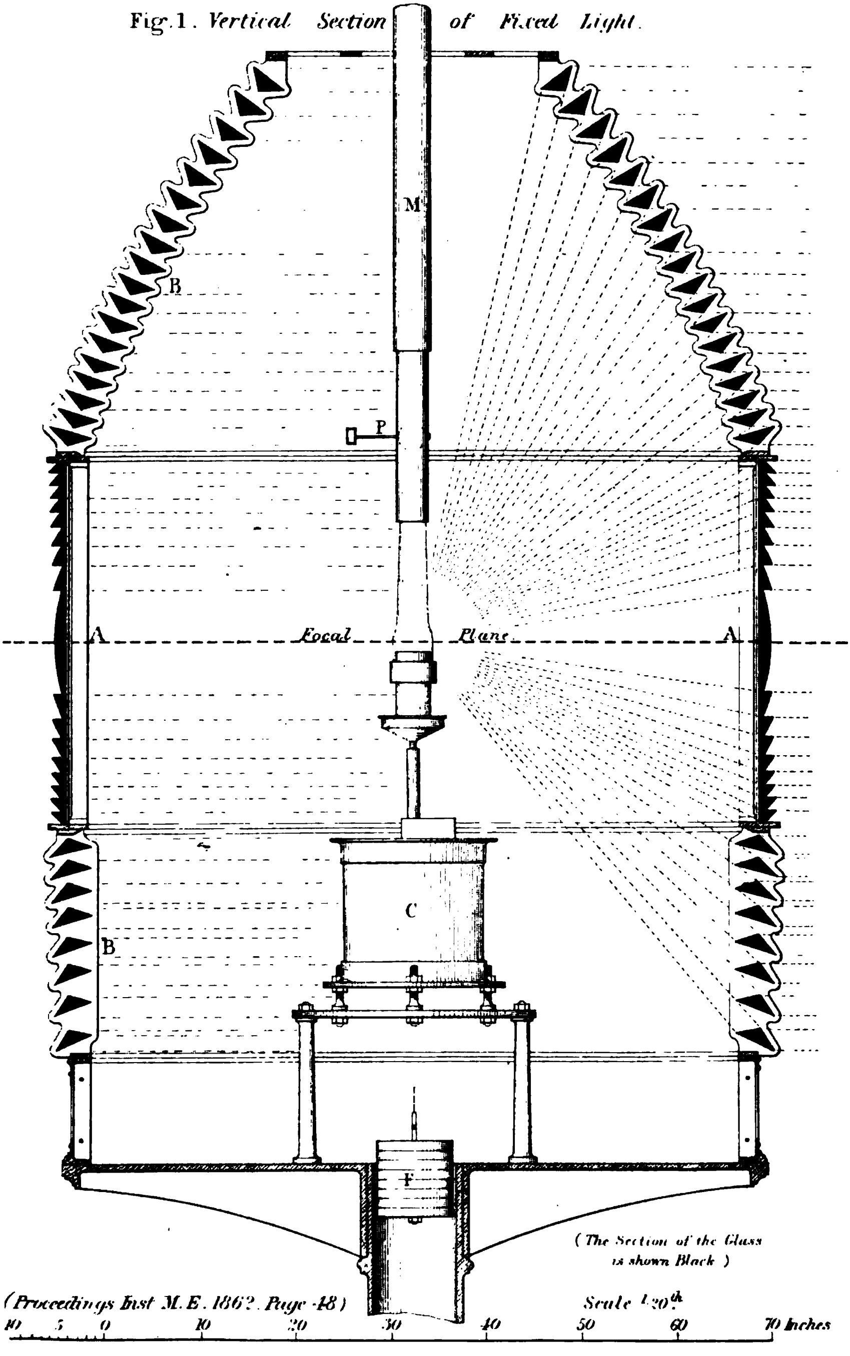
Scale 1/60th.



(Proceedings Inst. M. E. 1862. Page 21.)

LIGHTHOUSE APPARATUS. *Plate 13.*

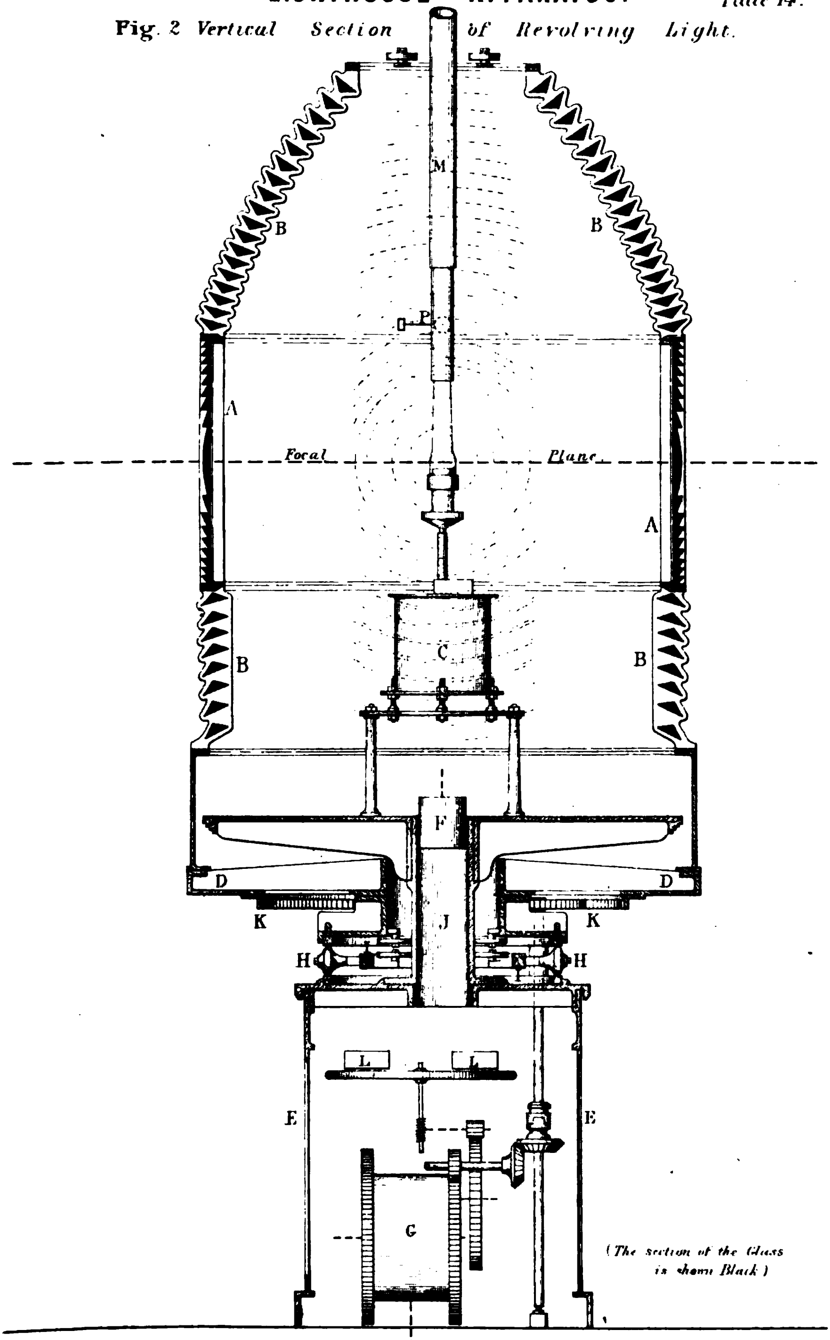
Fig. 1. *Vertical Section of Fixed Light.*



(Proceedings Inst M. E. 1862. Page 48)

LIGHTHOUSE APPARATUS.

Fig. 2 *Vertical Section of Revolving Light.*



(Proceedings Inst. M.E. 1862. Page 48)

Scale $1/30^{th}$

10 5 0 10 20 30 40 50 60 70 80 90 100 Inches.

Fig. 3. *Plan of Fixed Light.*

Scale 1/20th.

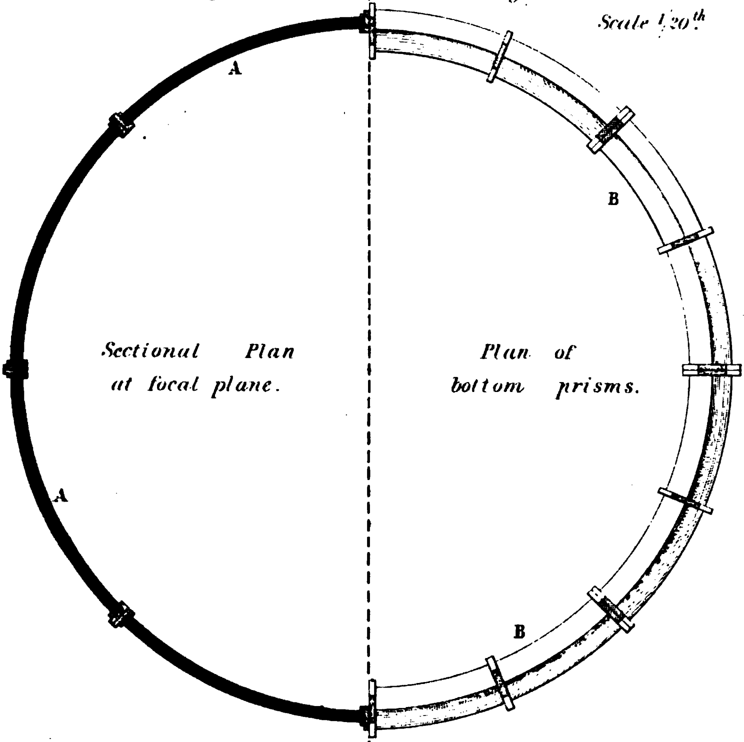
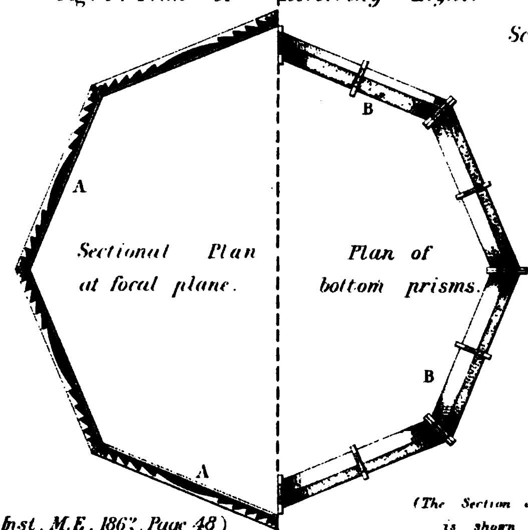


Fig. 4. *Plan of Revolving Light.*

Scale 1/30th.



(The Section of the Glass is shown Black.)

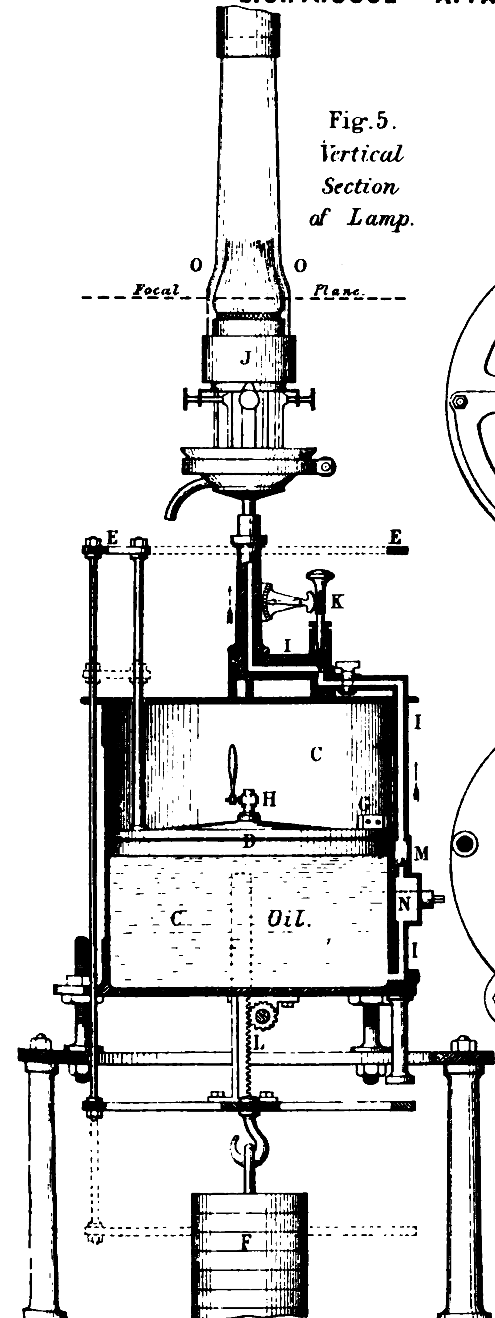


Fig. 5. Vertical Section of Lamp.

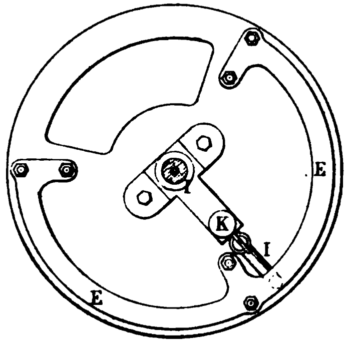


Fig. 6. Plan of Top of Cylinder.

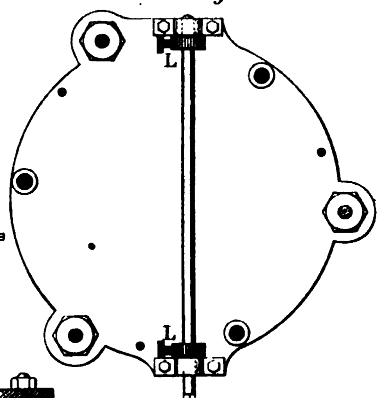


Fig. 7. Plan of Bottom of Cylinder.

Scale 1/10th 0 10 20 30 Inches.

Fig. 8. *Vertical Section of Lantern and Lightroom.*

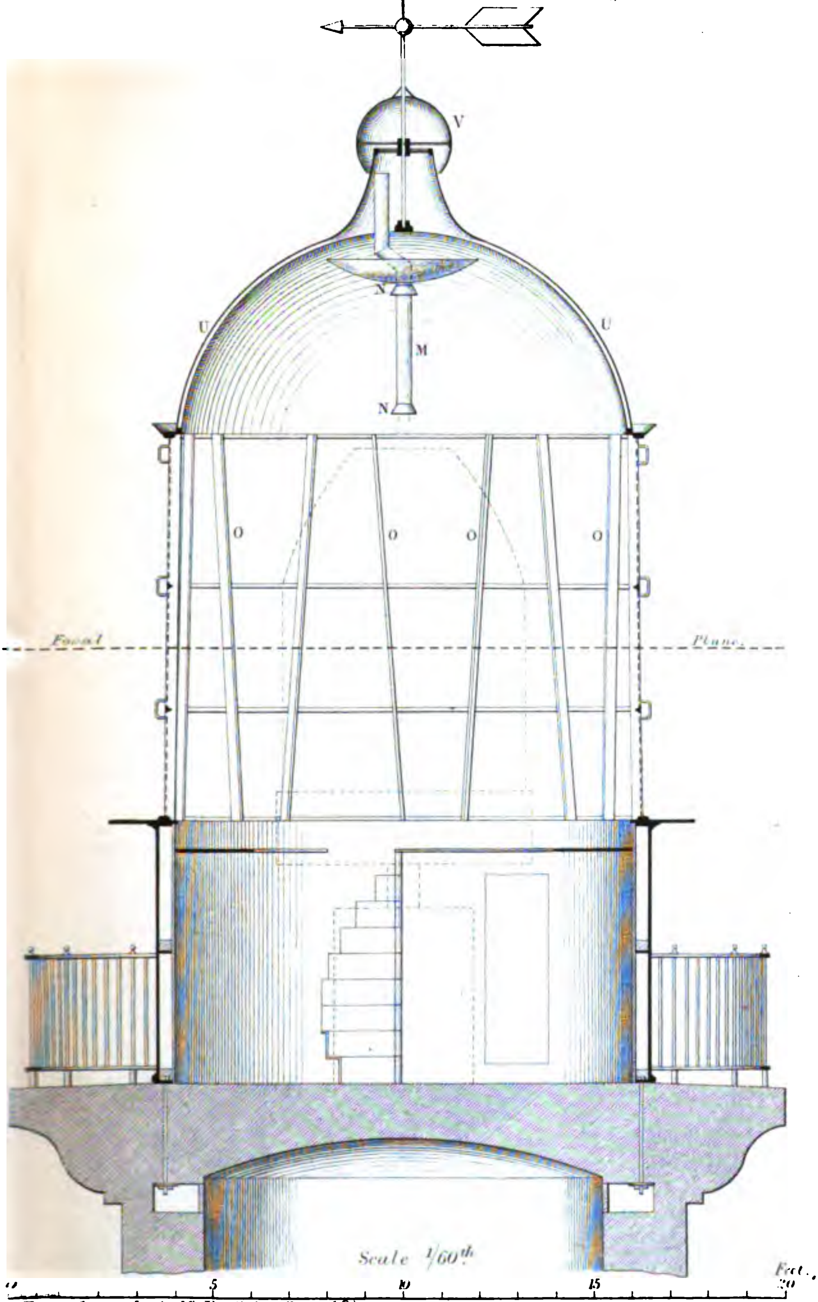
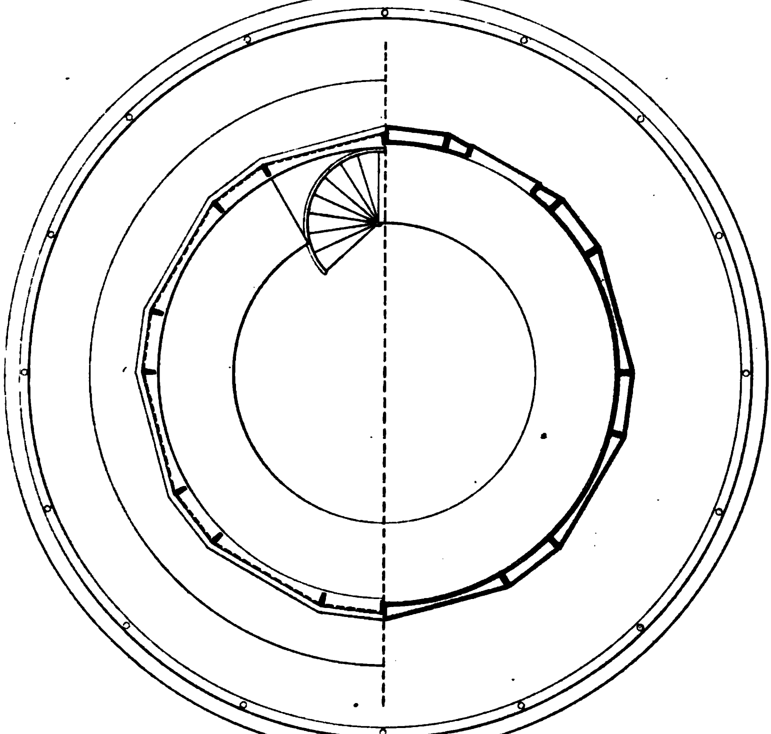


Fig. 9. Plan of Lightroom.



Scale 1/60th 0 5 10 15 Feet.

Details of Glazing and Framework of Lantern.

Fig. 10.

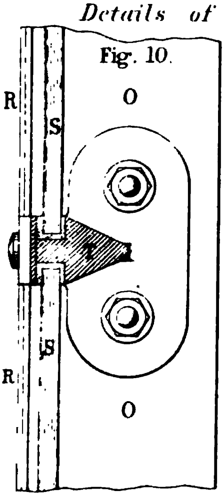


Fig. 11. Plan.

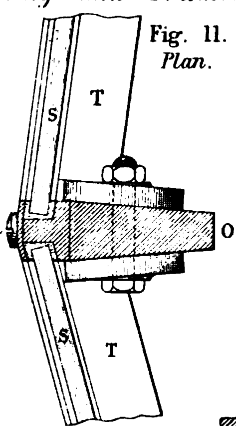
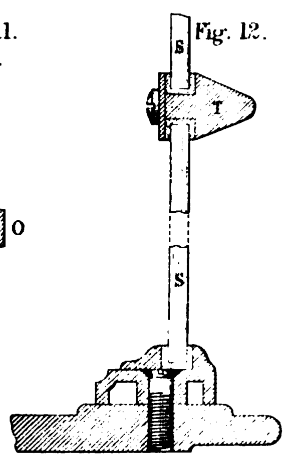
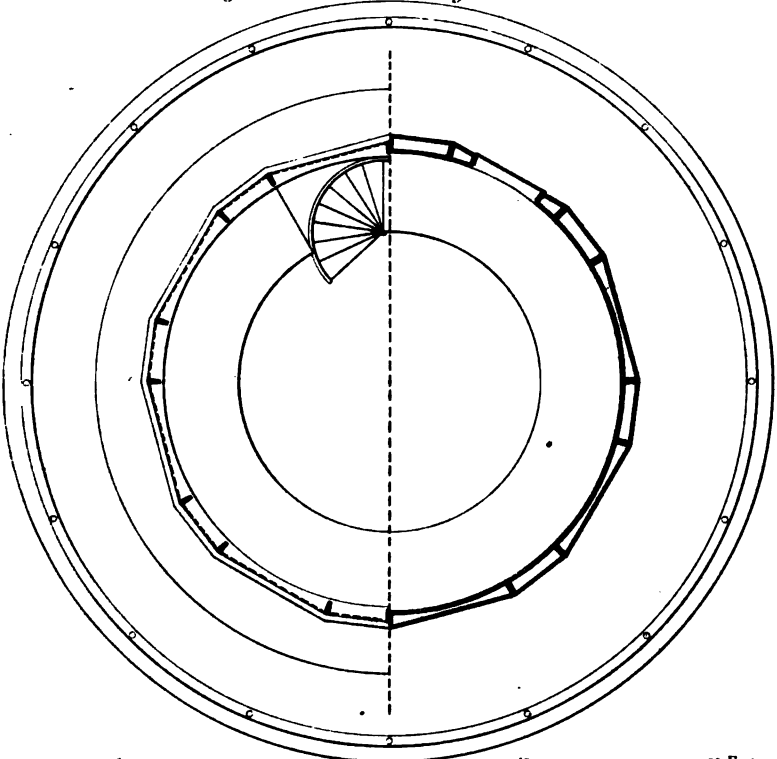


Fig. 12.



Scale 1/4th 0 1 2 3 4 5 Inches.

Fig. 9. *Plan of Lightroom.*



Scale 1/60th 0 5 10 15 *Feet.*

Details of Glazing and Framework of Lantern.

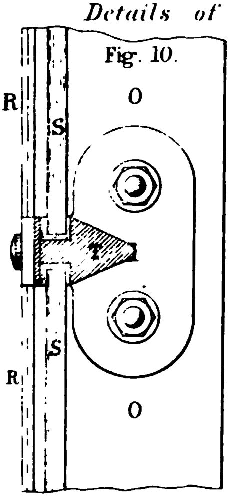


Fig. 10.

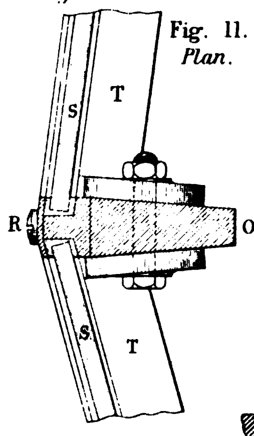


Fig. 11.
Plan.

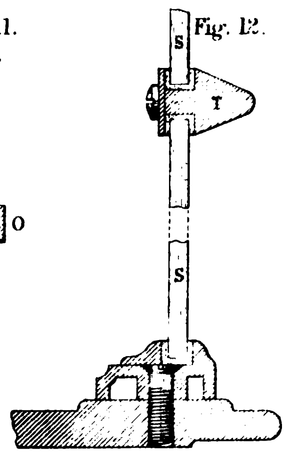


Fig. 12.

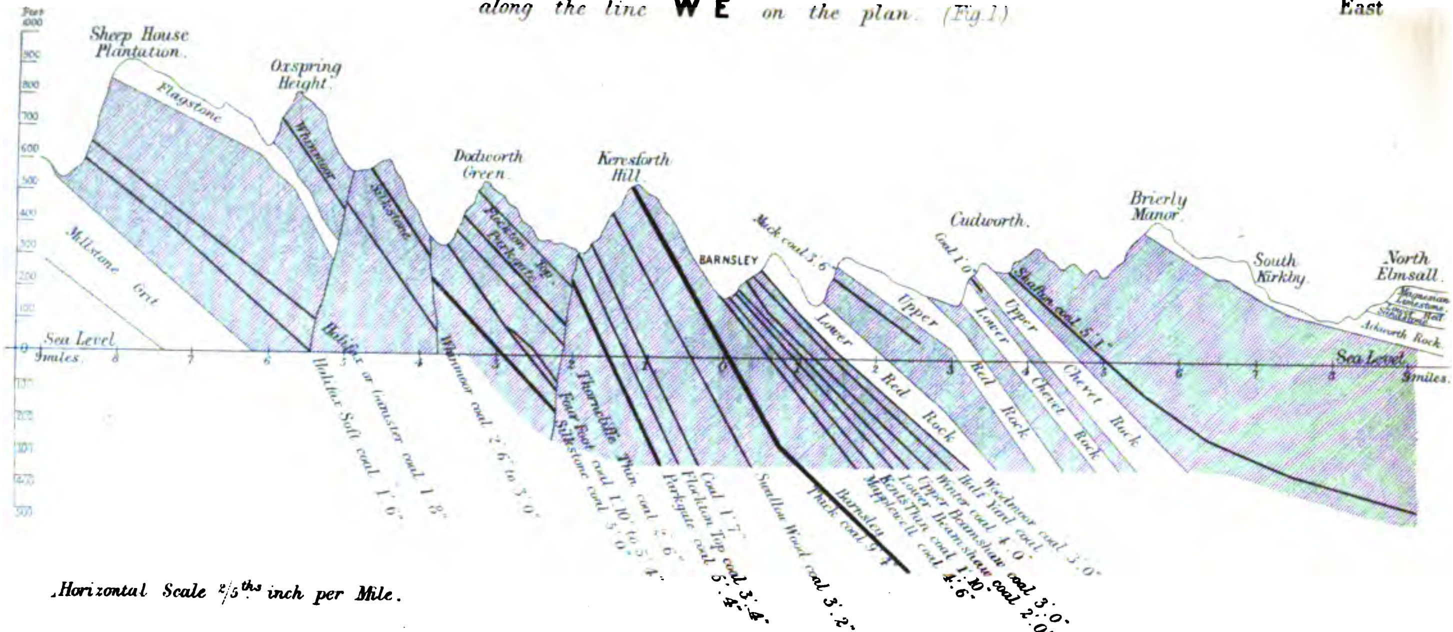
Scale 1/4th 0 1 2 3 4 5 *Inches.*

(Proceedings Inst. M. E. 1862. Page 48.)

SOUTH YORKSHIRE COAL MINING.

Plate 20.

Fig. 2. *Section of South Yorkshire Coalfield from West to East along the line* W E *on the plan. (Fig. 1)*



Horizontal Scale 2/5ths inch per Mile.

(Proceedings Inst. M. E. 1862. Page 68)

SOUTH YORKSHIRE COAL MINING.

Plate 21.

Vertical Section of Strata in South Yorkshire Coalfield.

Fig. 3. At Wath Wood.

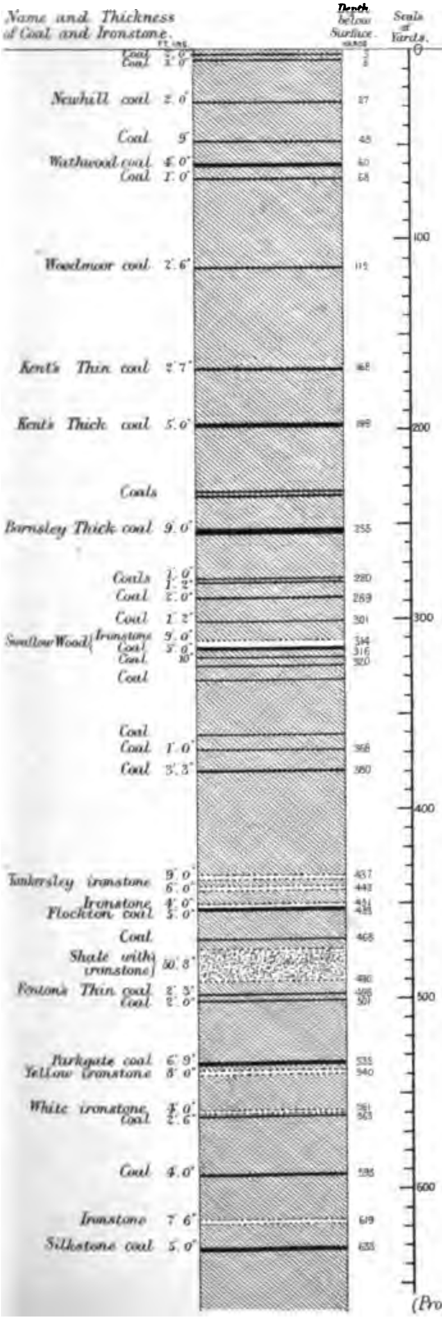
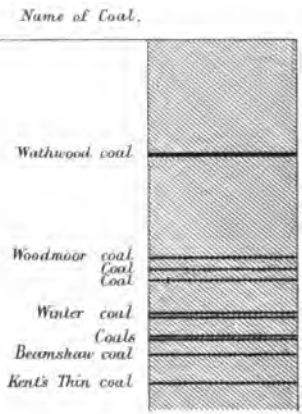


Fig. 4. At the Oaks Colliery.



Scale 1/3600th.

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Fig. 5. Plan of Narrow Work, on the End of the coal.

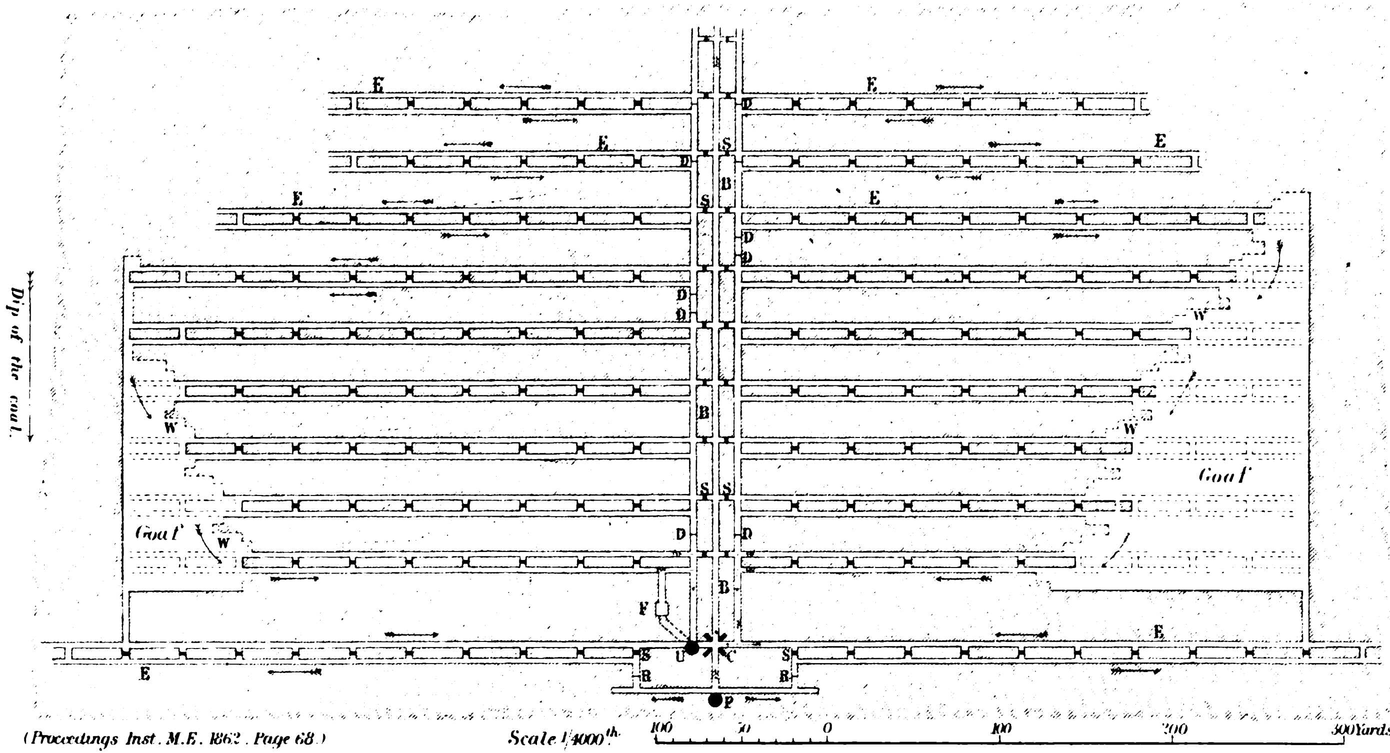
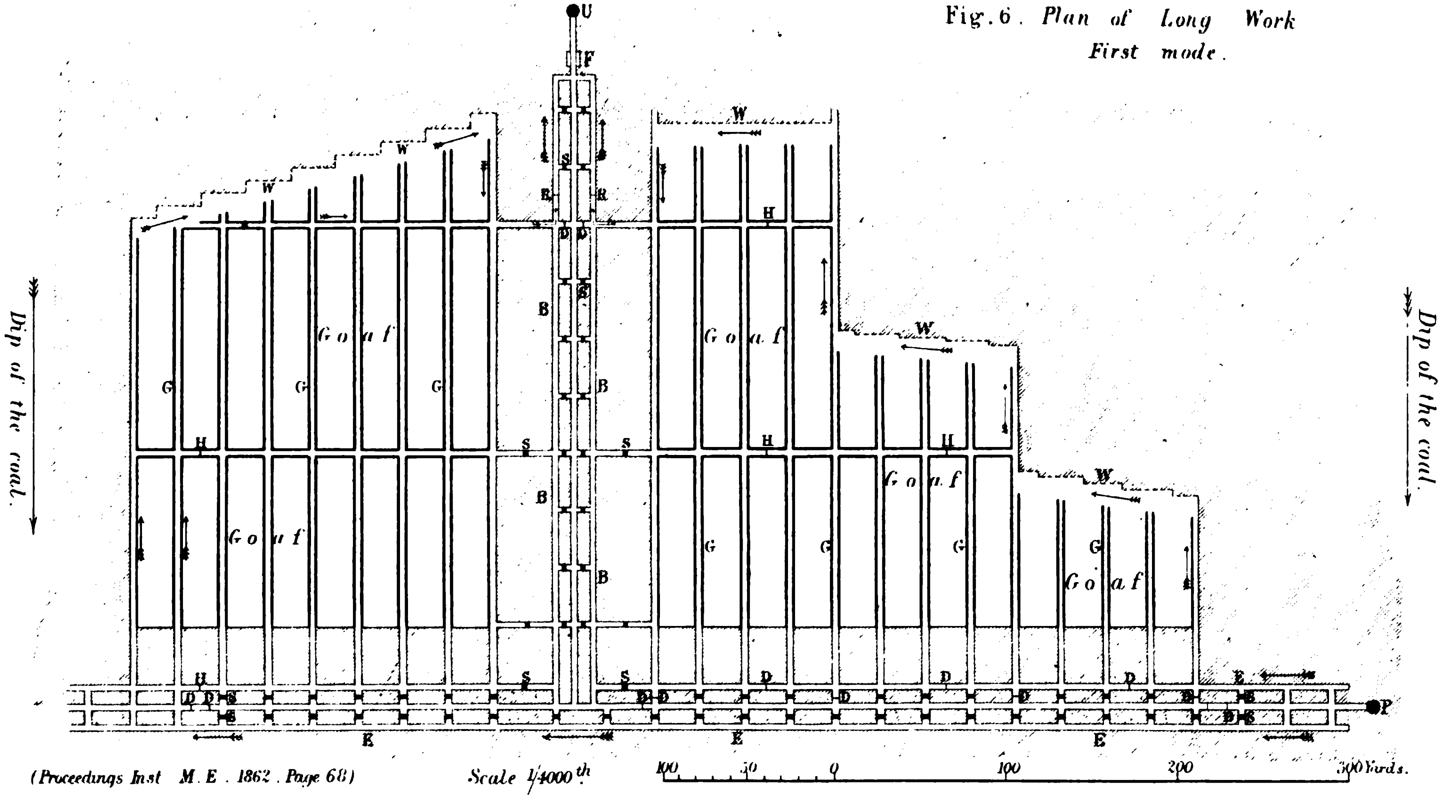


Fig. 6. *Plan of Long Work*
First mode.

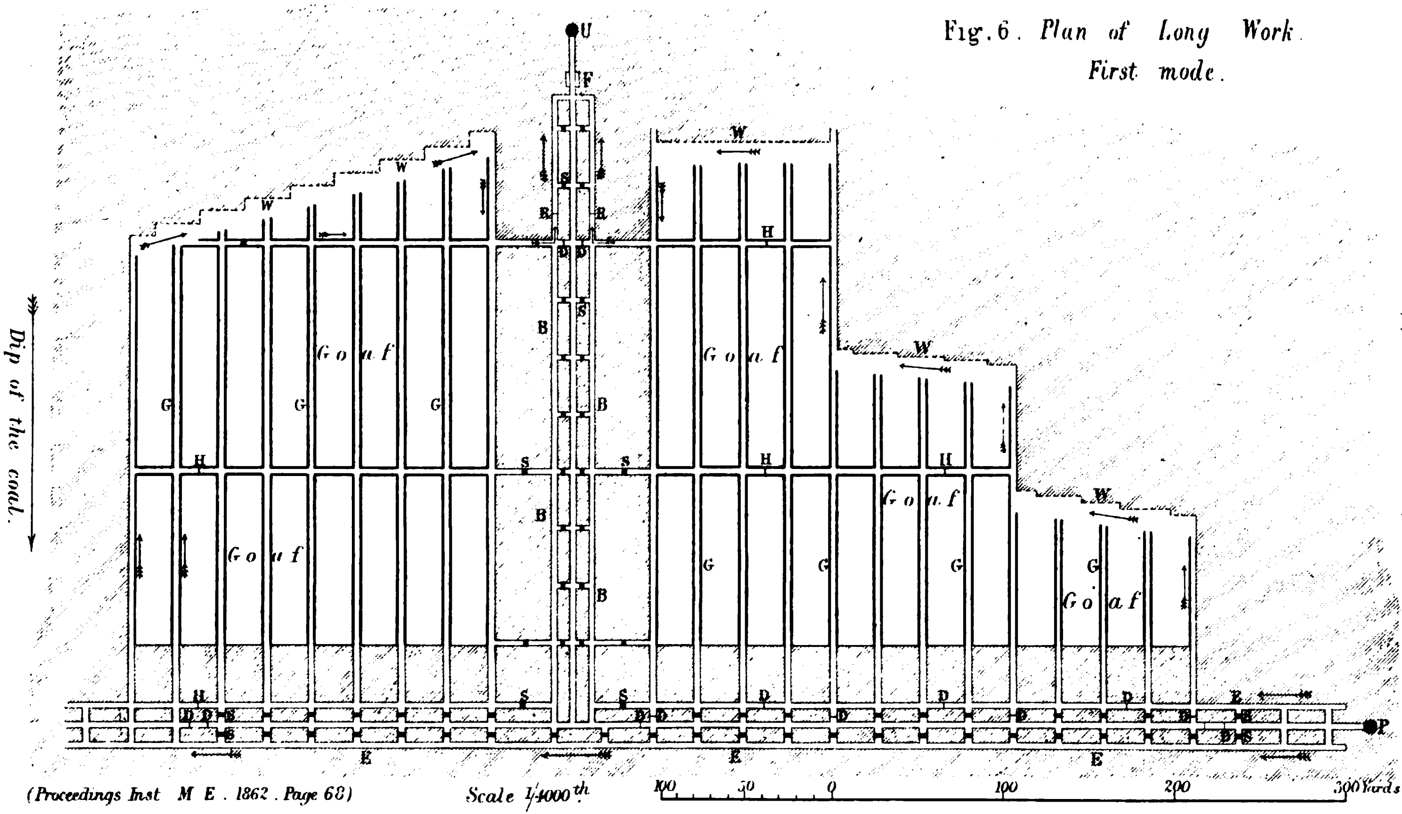


(Proceedings Inst M. E. 1862. Page 68)

SOUTH YORKSHIRE COAL MINING.

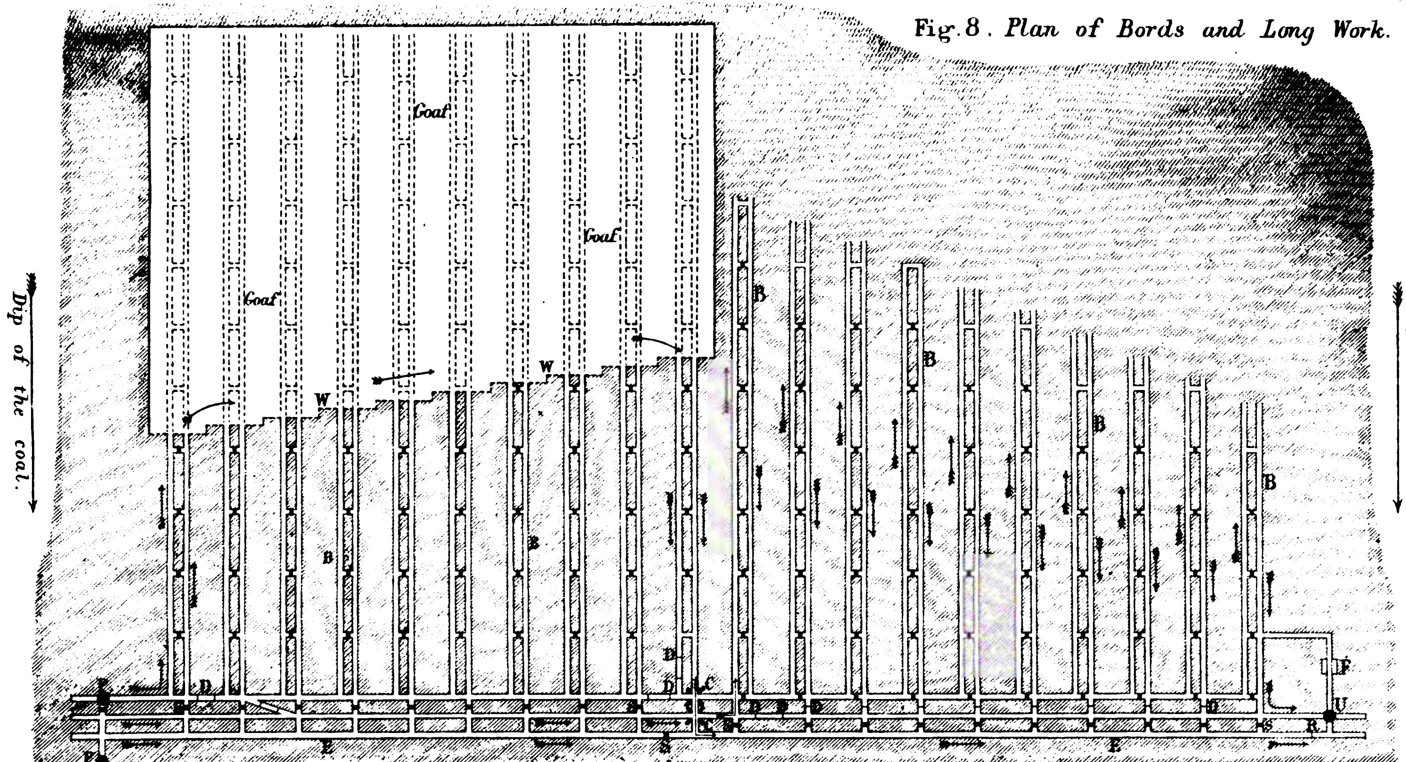
Plate 3.

Fig. 6. *Plan of Long Work.*
First mode.



(Proceedings Inst M E . 1862 . Page 68)

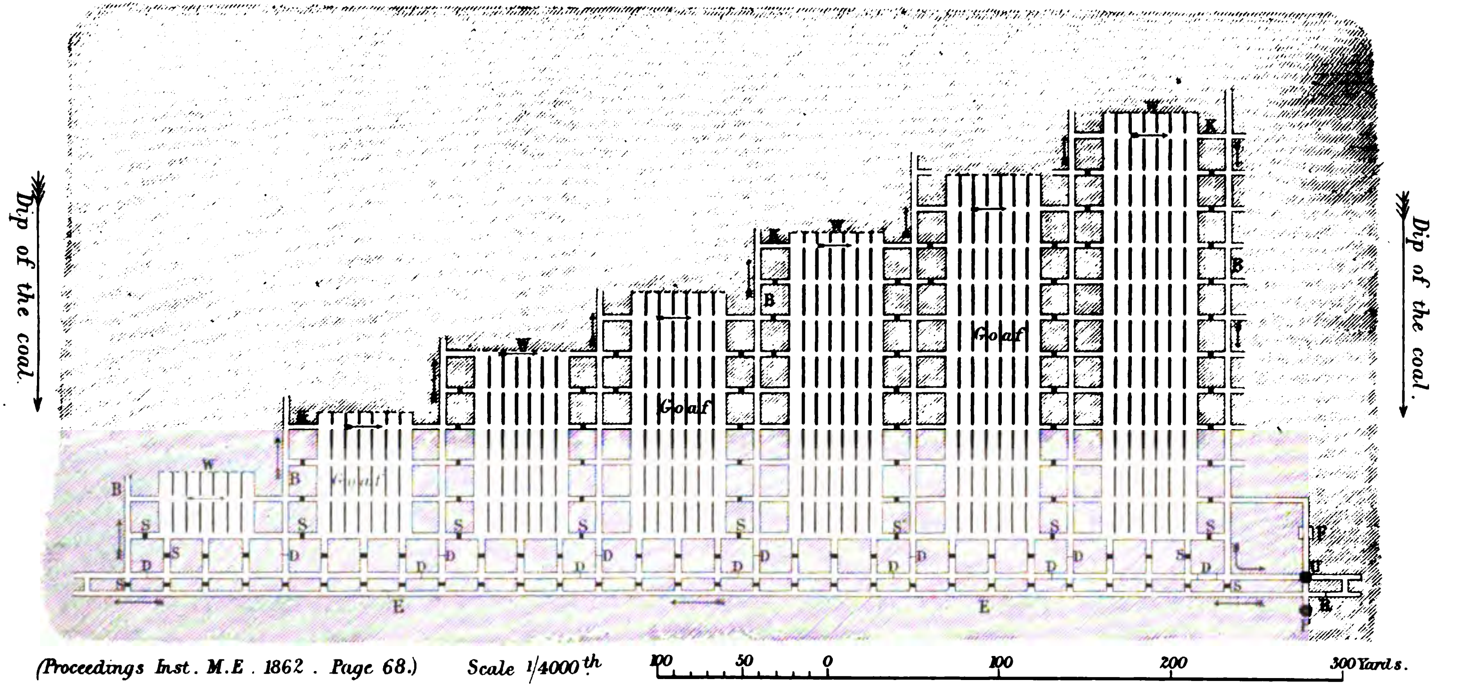
Fig. 8. Plan of Bords and Long Work.



(Proceedings Inst. M.E. 1862. Page 68.)

SOUTH YORKSHIRE COAL MINING. Plate 26.

Fig. 9. *Plan of Wide Work.*

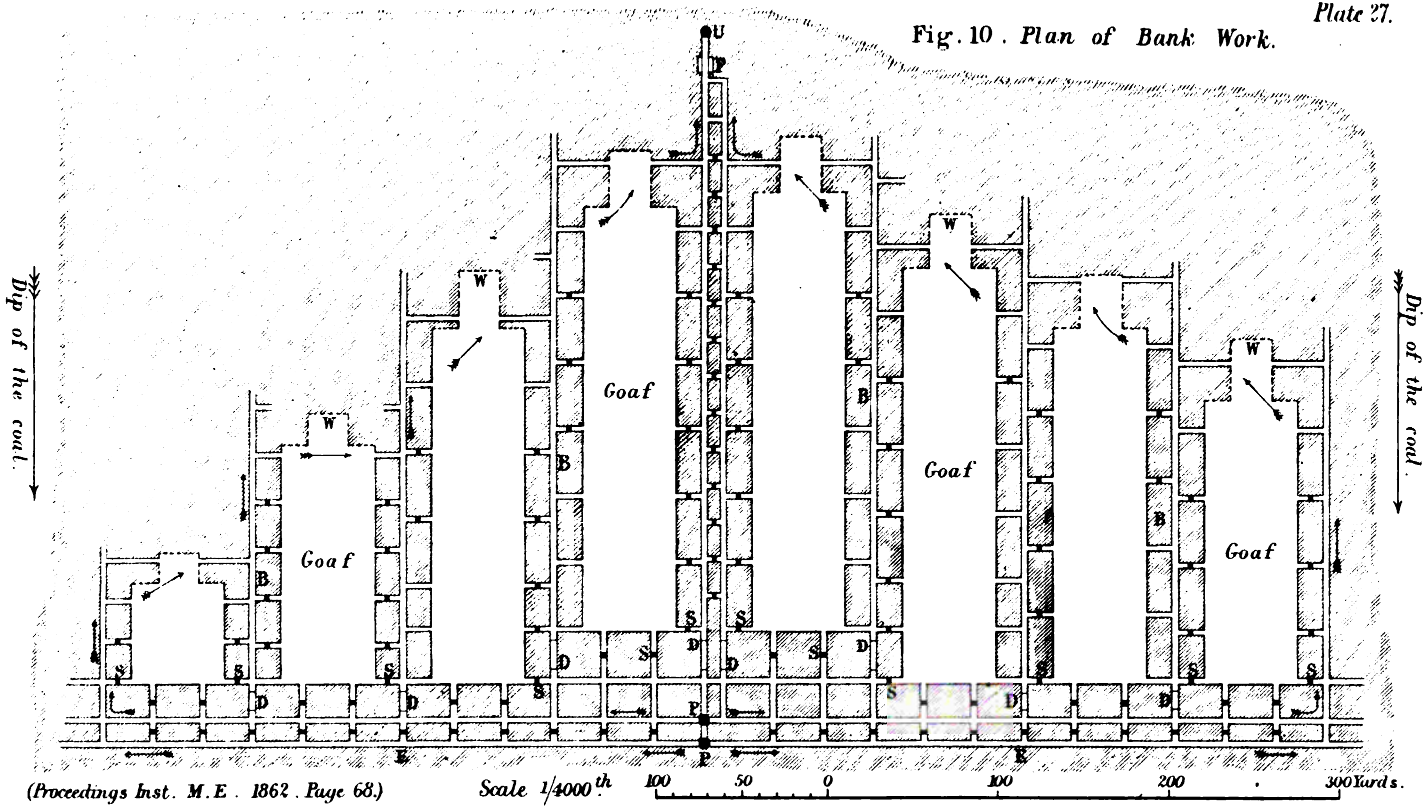


(Proceedings Inst. M.E. 1862. Page 68.) Scale 1/4000th.

SOUTH YORKSHIRE COAL MINING.

Plate 27.

Fig. 10. *Plan of Bank Work.*



(Proceedings Inst. M.E. 1862. Page 68.)

SOUTH YORKSHIRE COAL MINING.

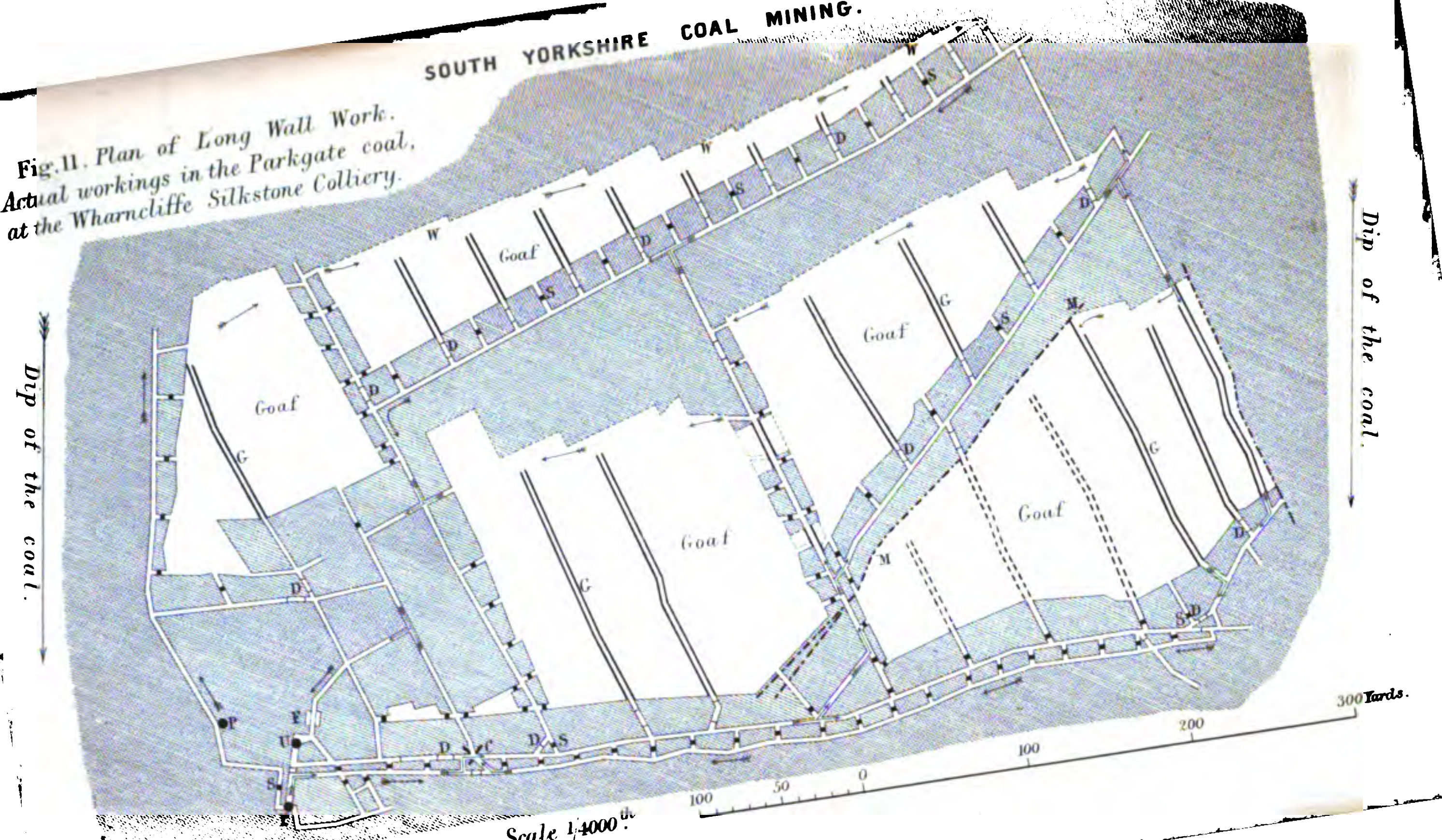


Fig. 11. Plan of Long Wall Work.
Actual workings in the Parkgate coal,
at the Wharncliffe Silkstone Colliery.

(Proceedings Inst. M. E. 1862. Page 68.)

SOUTH YORKSHIRE COAL MINING.

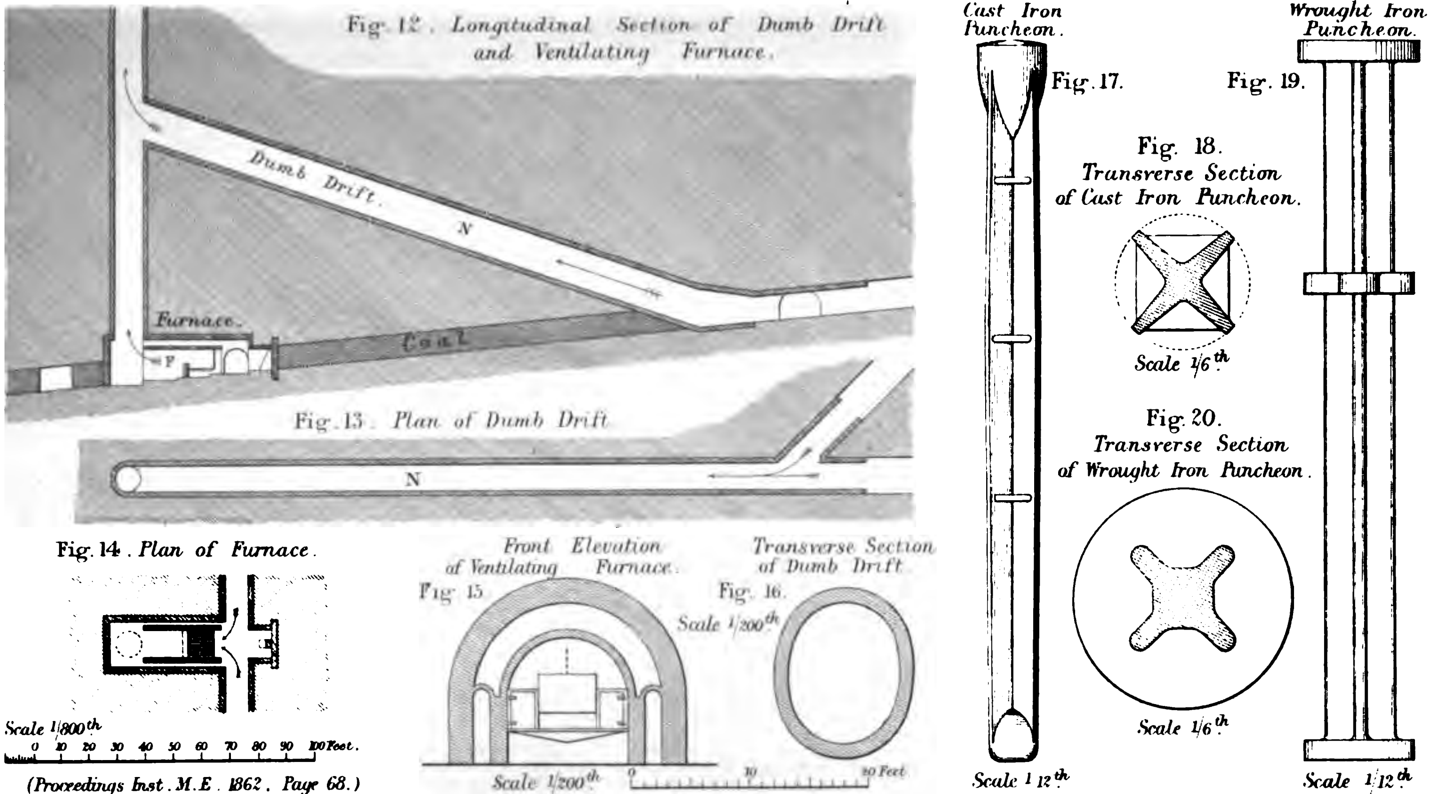


Fig. 12. Longitudinal Section of Dumb Drift and Ventilating Furnace.

Fig. 13. Plan of Dumb Drift.

Fig. 14. Plan of Furnace.

Fig. 15. Front Elevation of Ventilating Furnace.

Fig. 16. Transverse Section of Dumb Drift.

Fig. 17.

Fig. 18. Transverse Section of Cast Iron Puncheon.

Fig. 19.

Fig. 20. Transverse Section of Wrought Iron Puncheon.

Plate 29.

(Proceedings Inst. M.E. 1862. Page 68.)

FEED – PIPE CONNEXION.

Plate 30.

Fig. 1.

Elevation of Connecting Tube between engine and tender.

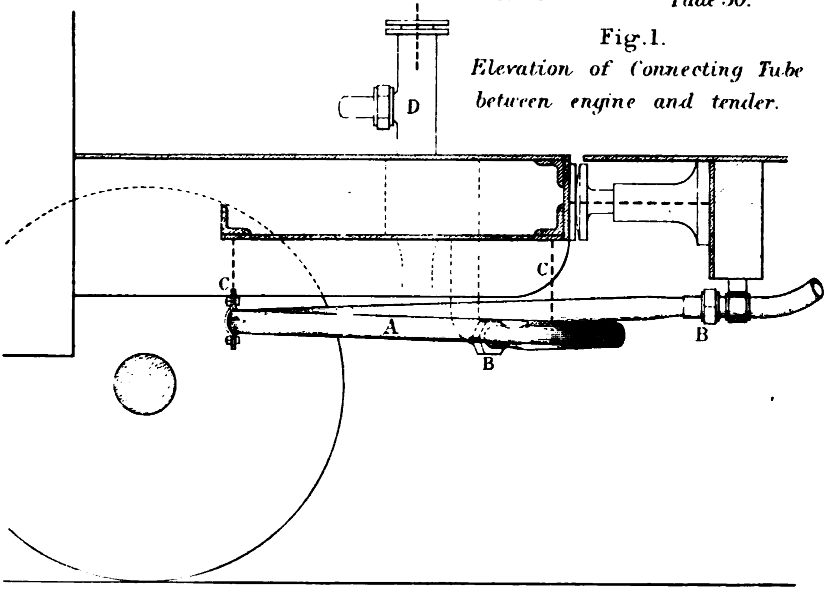
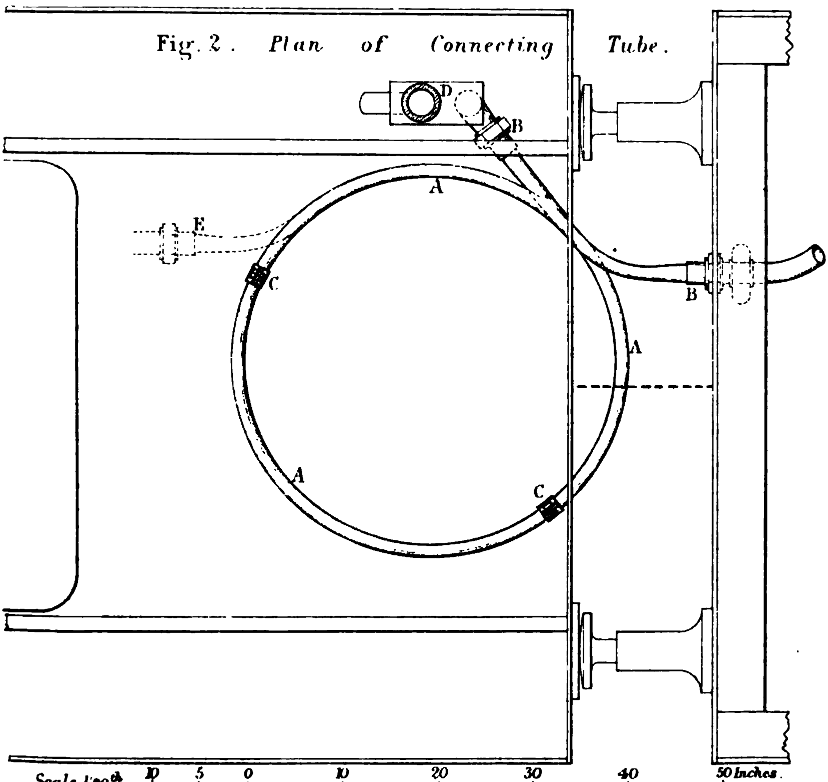


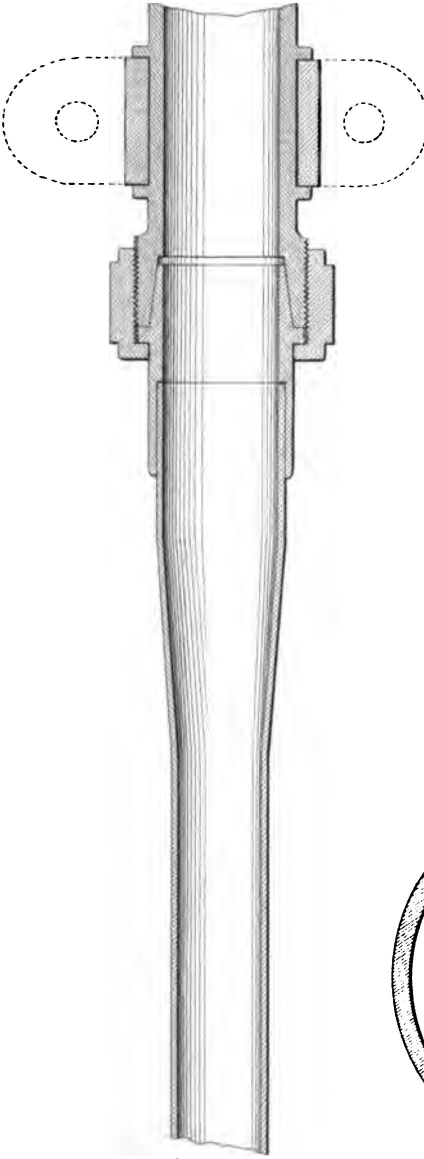
Fig. 2. *Plan of Connecting Tube.*



Scale 1/20th.

(Proceedings Inst. M. E. 1862. Page 88.)

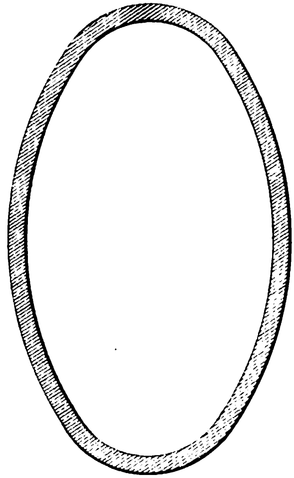
Fig. 3.
Sectional Plan of End of Connecting Tube.



Scale 1/3rd full size.

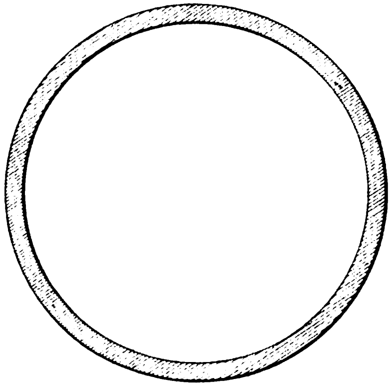
(Proceedings Inst. M. E. 1862. Page 88.)

Fig. 4.
Section of Elliptical Tube.



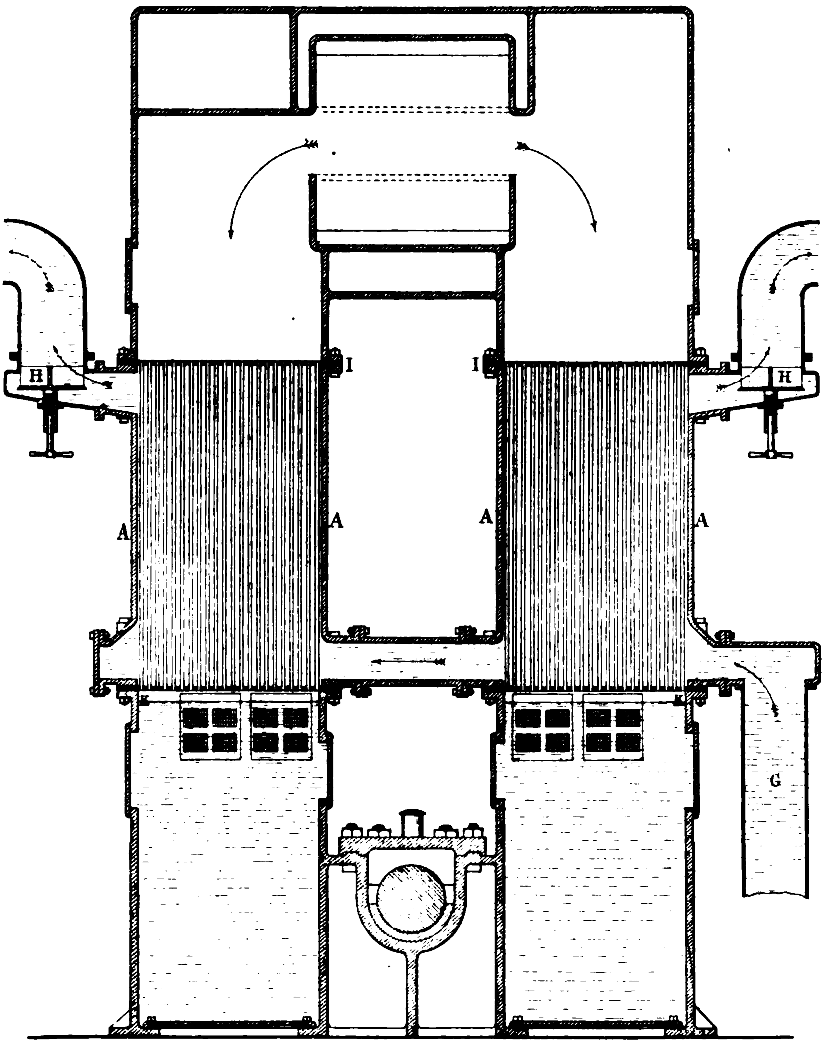
Full size.

Fig. 5.
Section of Circular Tube.



Full size.

Fig. 1. *Thwartship Section through Condensers.*



Scale 1/40th

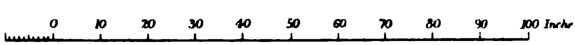
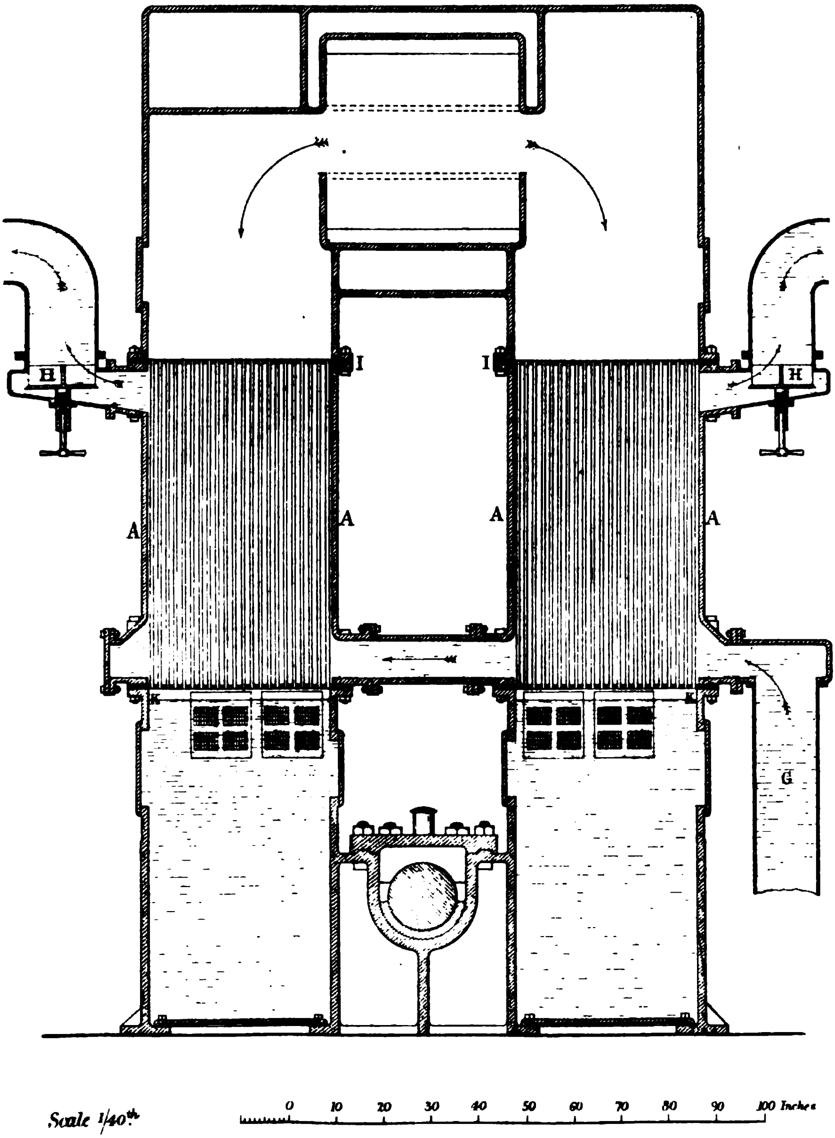


Fig. 1. *Thwartship Section through Condensers.*



SURFACE CONDENSER.

Fig. 3. Detail of fixing of Tubes. Full size.

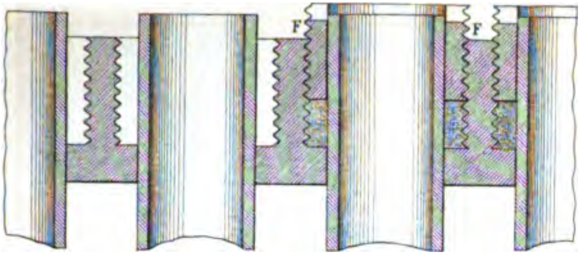


Fig. 4. Plan.

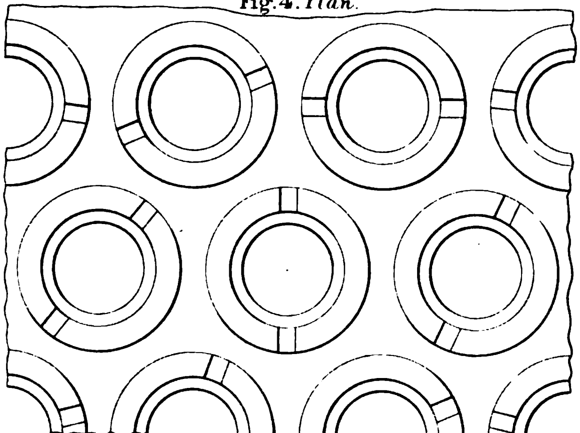


Fig. 5. Screwed Gland.

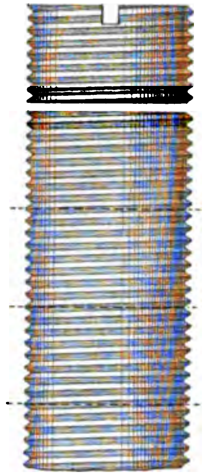
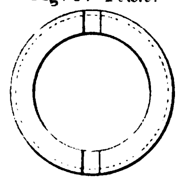


Fig. 6. Plan.



Full size

Fig. 7. Drill. Fig. 9. Tap.

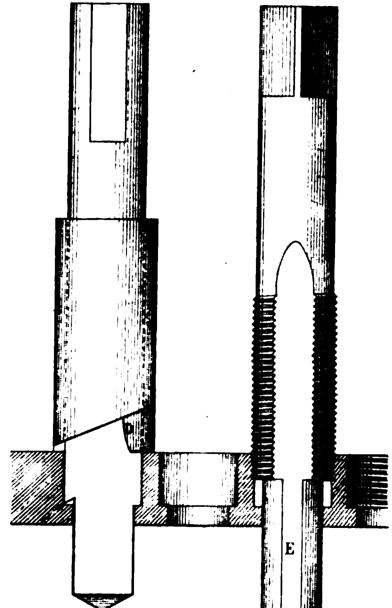


Fig. 8. Plan.

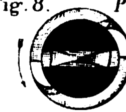


Fig. 10. Plan

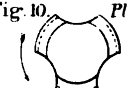


Fig. 11. Facing Cutter for glands.

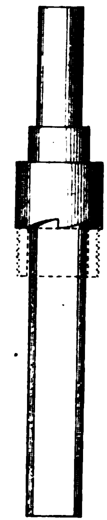
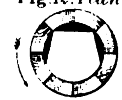


Fig. 12. Plan.



Half full size.

(Proceedings Inst. M. E. 1862. Page 99.)

Indicator Diagrams from engines of "Mooltan." 1861.
Vacuum in condensers 28 inches of mercury.
Pressure of steam in boilers 17 lbs. 58 Revolutions per minute.

Fig. 13. *Indicator Diagram from Top of cylinder.*

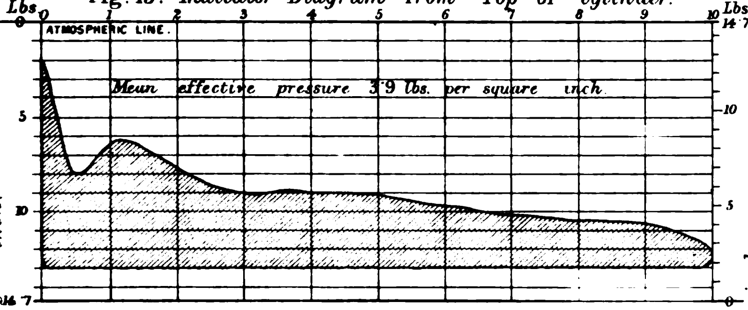


Fig. 14. *Indicator Diagram from Bottom of cylinder.*

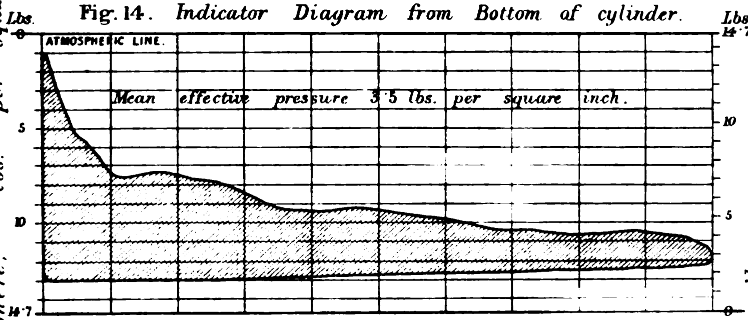
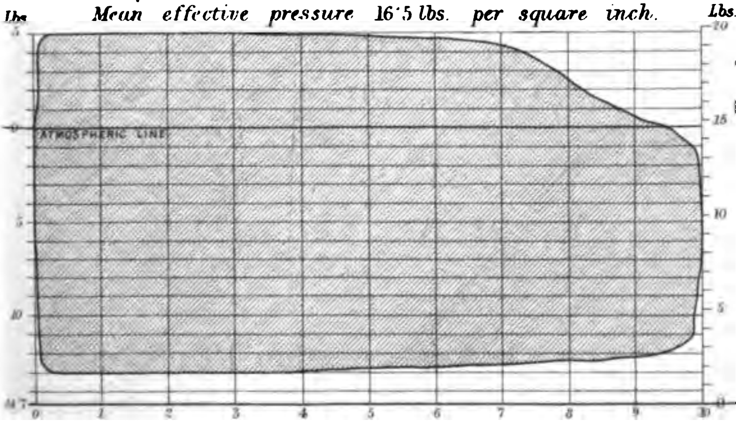


Fig. 15. *Indicator Diagram from engines of "Wilberforce." 1838.*
Vacuum in condensers 28 inches of mercury.
Pressure of steam in boilers 6 lbs. 19 Revolutions per minute.
Cylinders 60 inches diam., 6 feet stroke.
Mean effective pressure 16·5 lbs. per square inch.



(*Proceedings Inst. M. E. 1862. Page 99.*)

RIFLED GUN MANUFACTURE.

Fig. 1. *Side Elevation of Rifling Machine.*

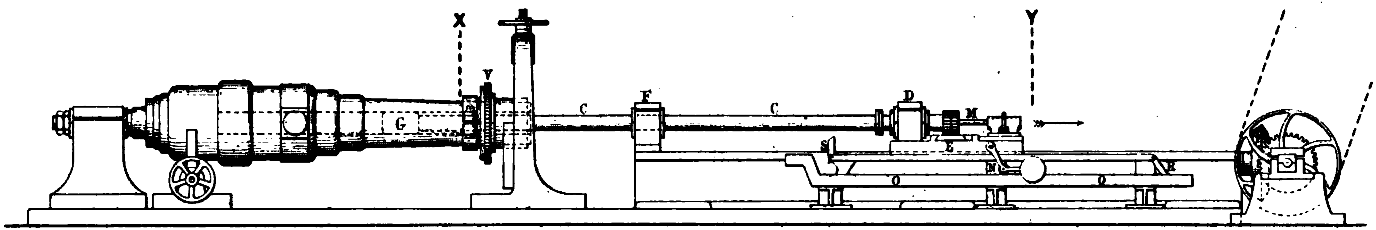
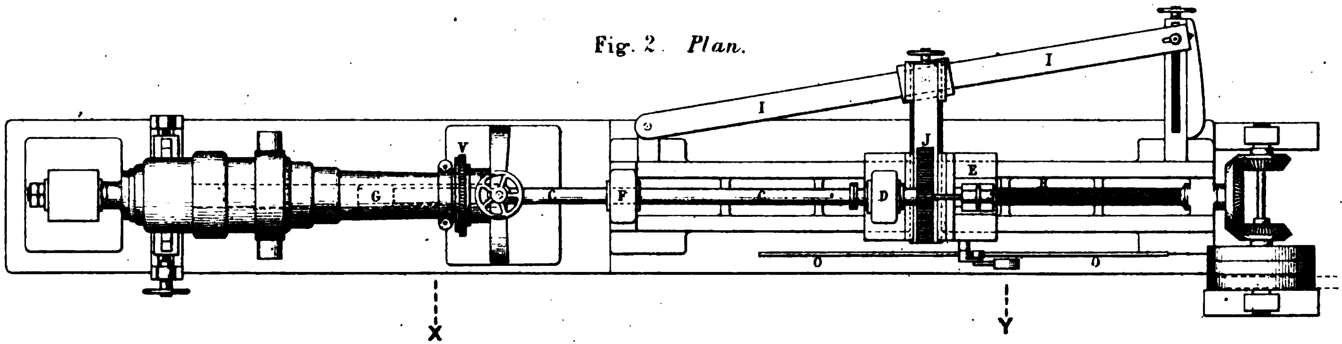


Fig. 2. *Plan.*



 Scale 1/60th.

RIFLED GUN MANUFACTURE.

Fig. 3.

Transverse Section at XX.

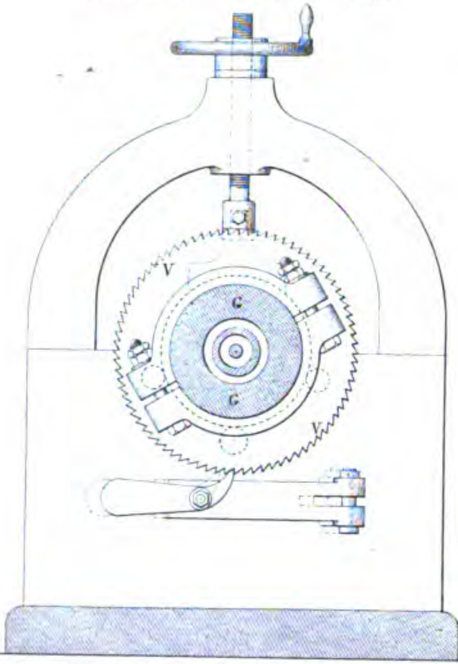


Fig. 5. Side Elevation of Traversing Saddle carrying Rifling Bar.

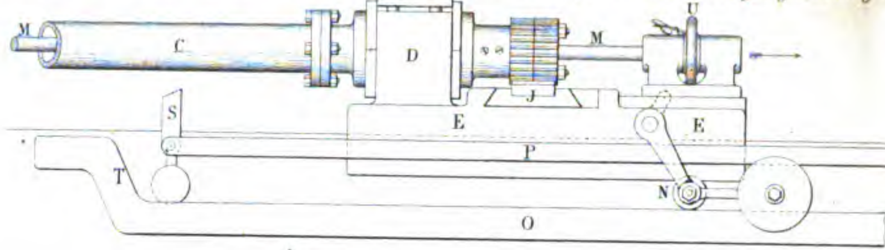
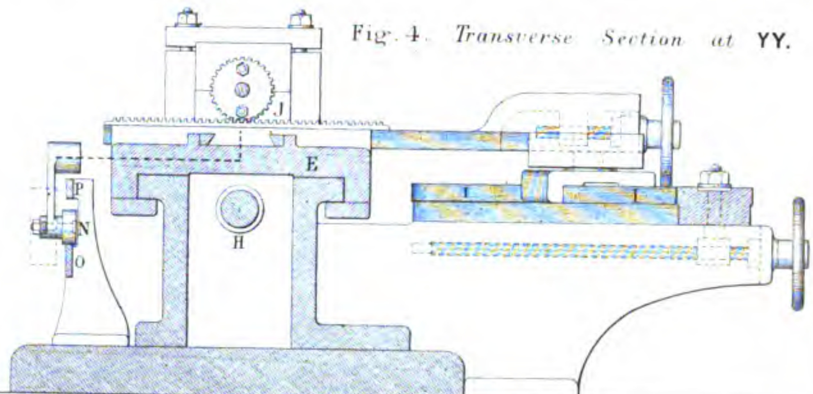


Fig. 4. Transverse Section at YY.



(Proceedings Inst. M.E. 1862 Page 125)

Scale 1/20th

10 5 0 10 20 30 40 50 Inches.

Fig. 3. Transverse Section at XX.

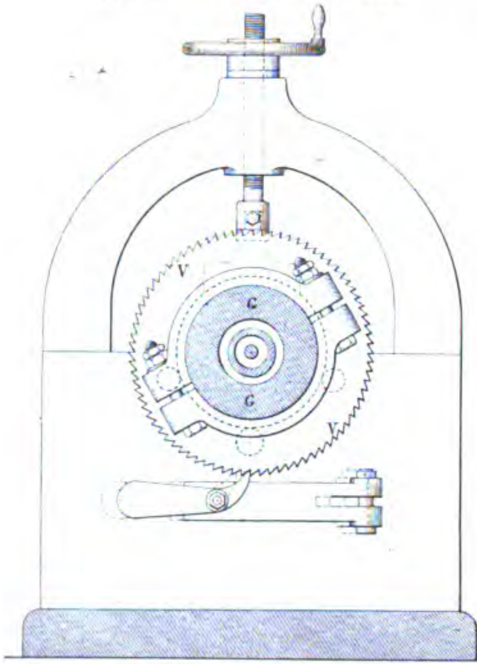


Fig. 5. Side Elevation of Traversing Saddle carrying Rifling Bar.

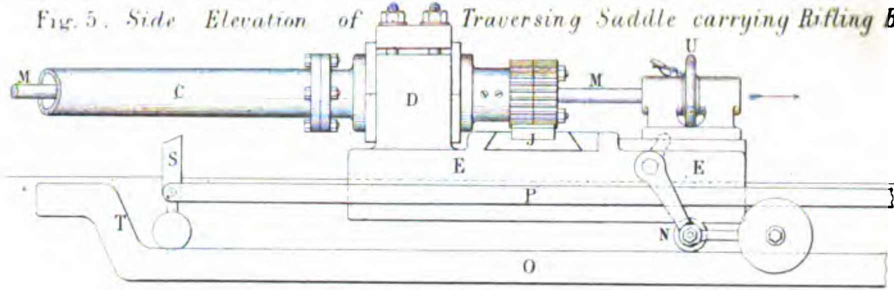
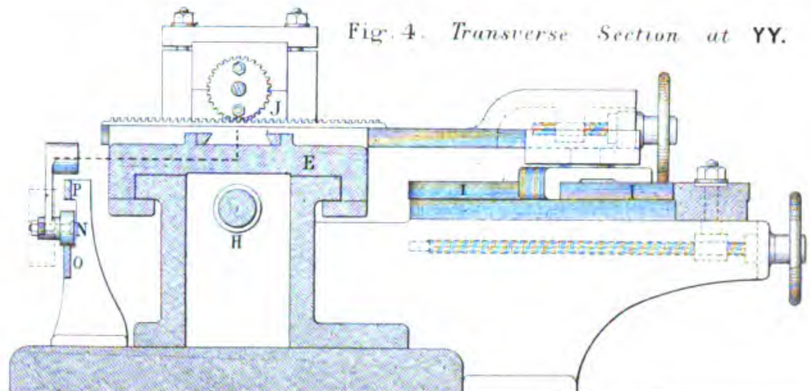


Fig. 4. Transverse Section at YY.



Scale 1/20th 10 5 0 10 20 30 40 50 Inches.

RIFLED GUN MANUFACTURE.

Fig. 7. Broaching Bar for final boring of gun. Scale 1/16th

Fig. 8. Twisted Rifling Bar. Scale 1/16th

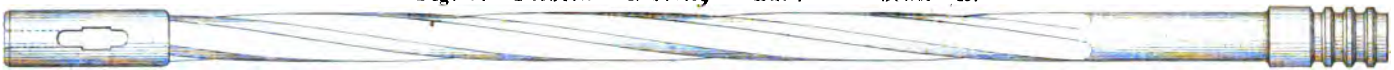
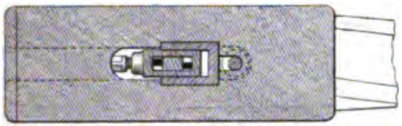


Fig. 11. Rifling Head with fixed cutters.



Head of Broaching Bar for final boring.

Fig. 10.

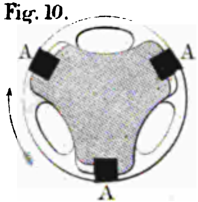


Fig. 9.

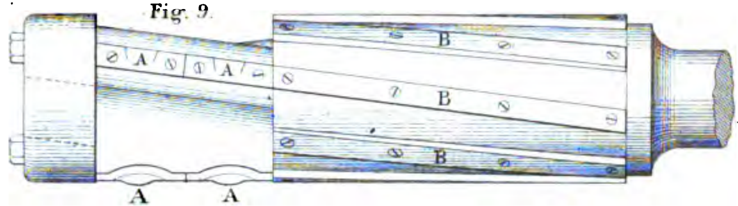


Fig. 12. Rifling Head with fixed cutters.

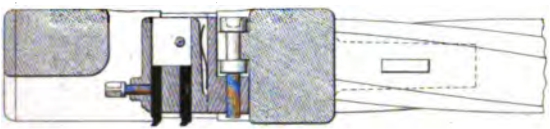
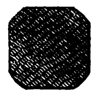


Fig. 13. Section of Twisted Rifling Bar.



Rifling Head with feed motion for cutter.

Fig. 14.

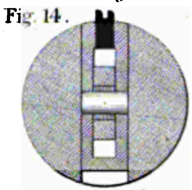
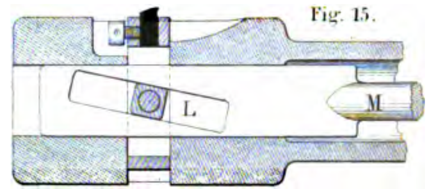


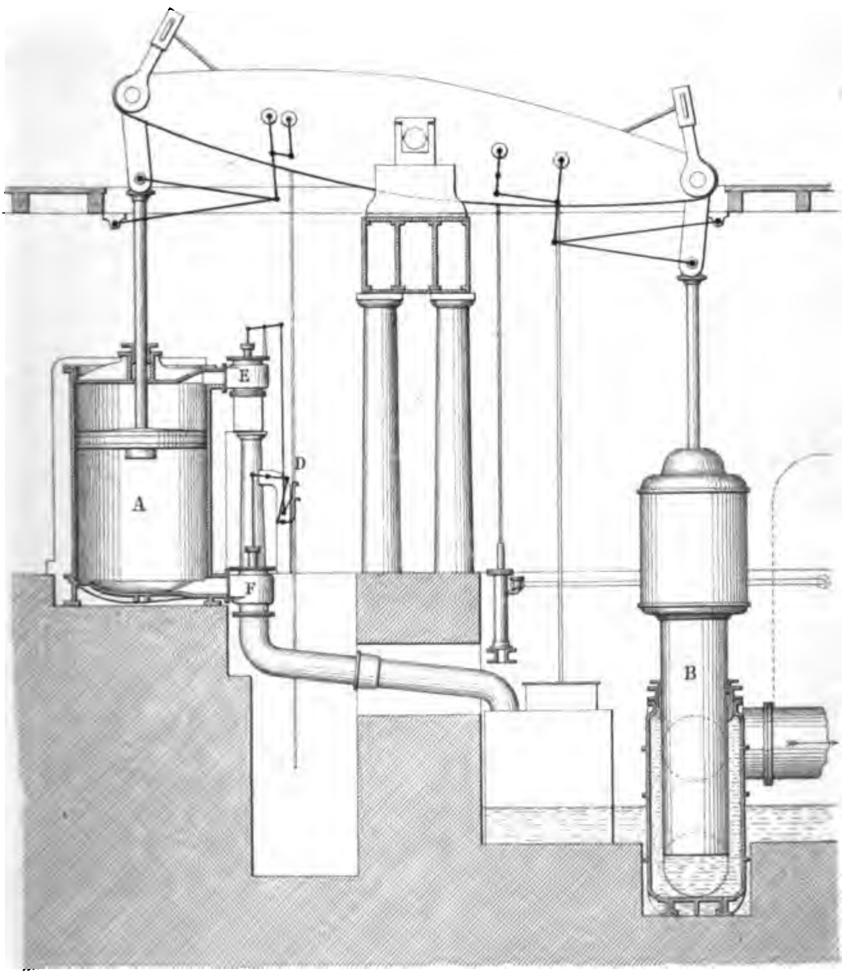
Fig. 15.



Scale 1/8th

0 10 20 30 Inches.

Fig. 1. *Longitudinal Section of Engine at East London Water Works.*

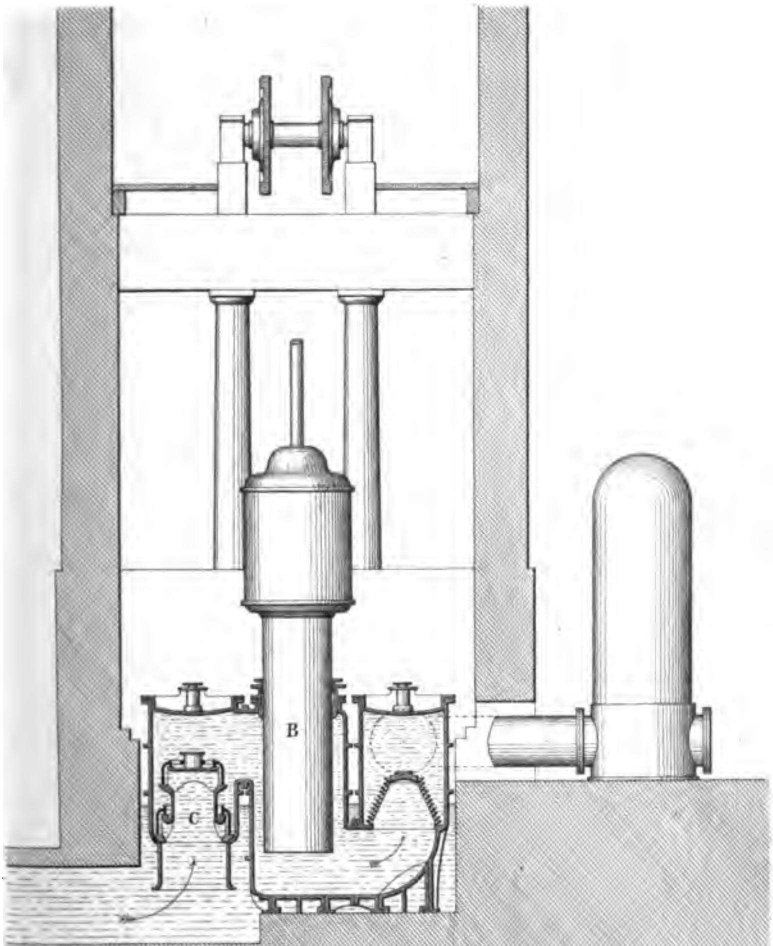


Scale 1/140th

10 5 0 10 20 30 Feet.

(Proceedings Inst. M. E. 1862. Page 147)

Fig. 2. *Transverse Section of Engine at East London Water Works.*



Scale 1/140th

CORNISH PUMPING ENGINES.

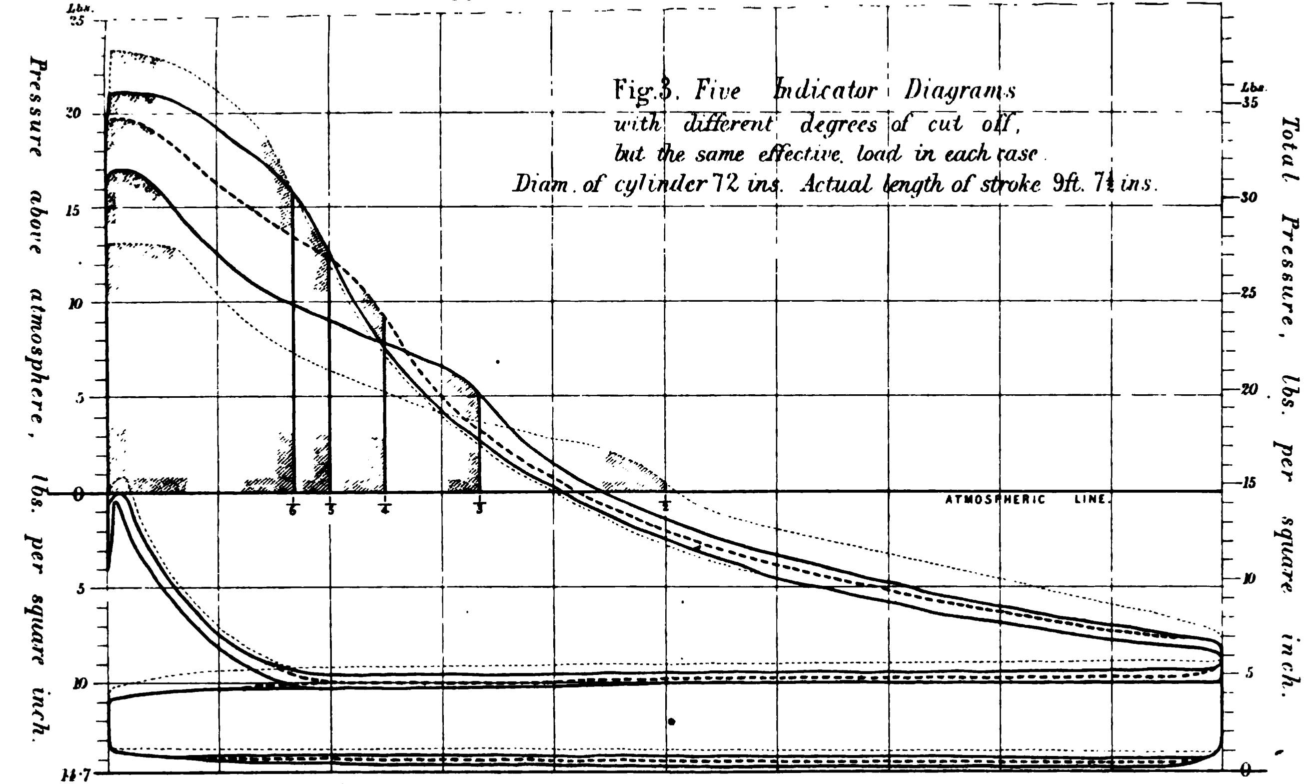


Fig. 3. Five Indicator Diagrams with different degrees of cut off, but the same effective load in each case. Diam. of cylinder 72 ins. Actual length of stroke 9ft. 7½ ins.

(Proceedings Inst. M.E. 1862. Page 147)

Indicator Diagrams from 72 inch cylinder.
Total Load equal to 15 lbs. per square inch on the piston.
Actual length of stroke 9 ft. 7½ ins.

Fig. 4. *Steam cut off at ½ stroke.*

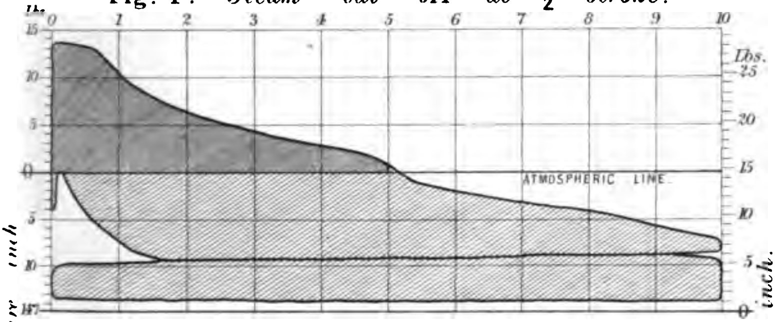


Fig. 5. *Steam cut off at ⅓ stroke.*

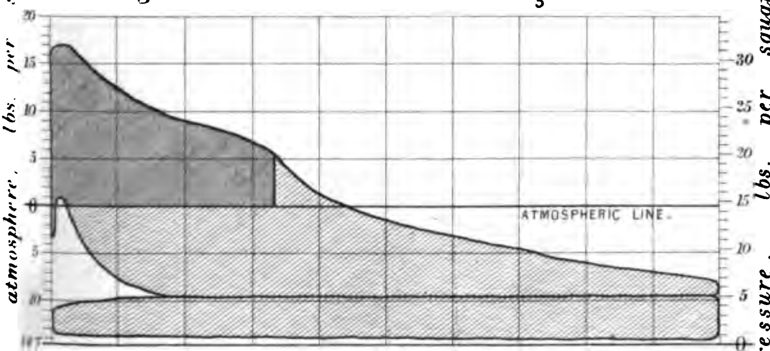
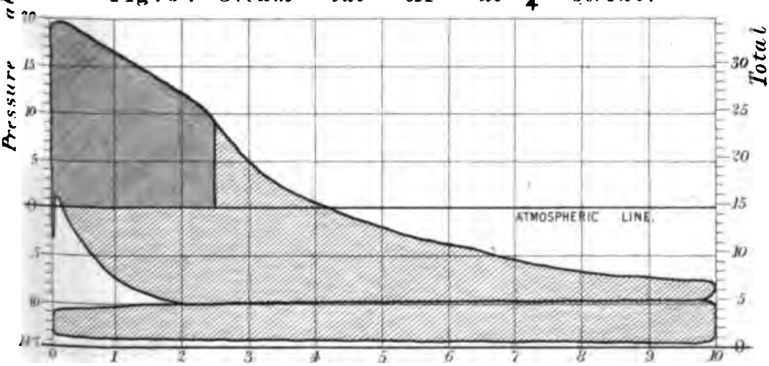


Fig. 6. *Steam cut off at ¼ stroke.*



(Proceedings Inst. M.E. 1862. Page 147)

Indicator Diagrams from 72 inch cylinder.
Total Load equal to 15 lbs. per square inch on the piston.
Actual length of stroke 9 ft. 7½ ins.

Fig. 4. *Steam cut off at ½ stroke.*

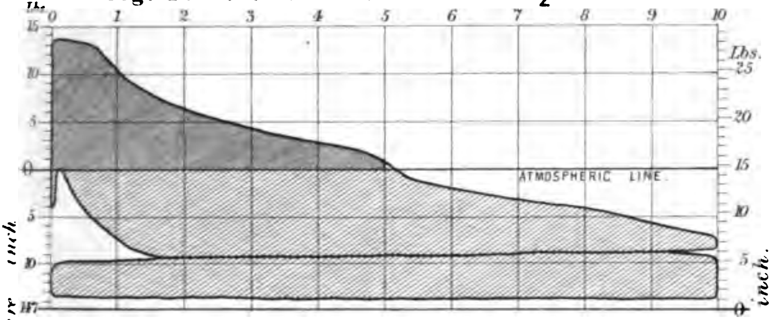


Fig. 5. *Steam cut off at ⅓ stroke.*

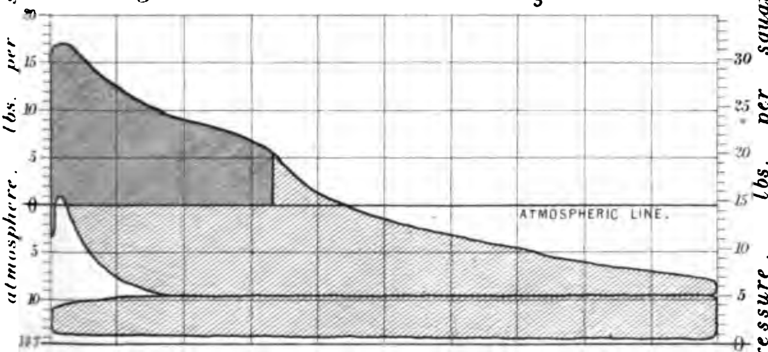
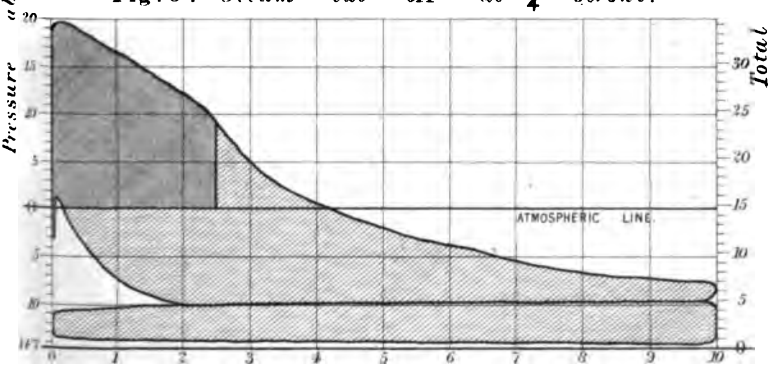


Fig. 6. *Steam cut off at ¼ stroke.*



(Proceedings Inst. M.E. 1862. Page 147)

Indicator Diagrams from 72 inch cylinder.
Total Load equal to 15 lbs. per square inch on the piston.
Actual length of stroke 9 ft. $7\frac{1}{2}$ ins.

Fig. 7. *Steam cut off at $\frac{1}{5}$ stroke.*

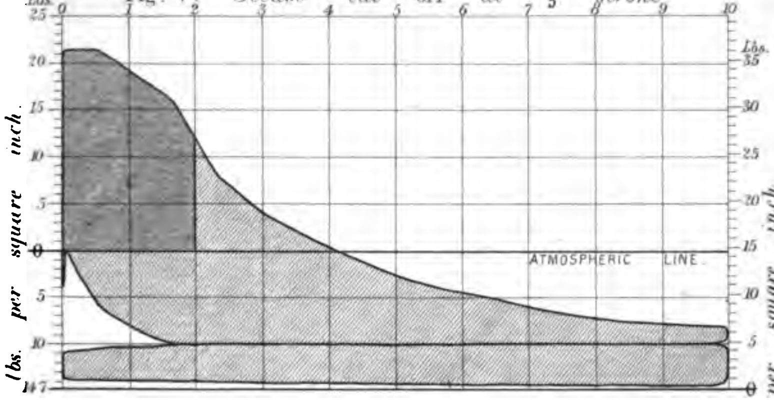


Fig. 8. *Steam cut off at $\frac{1}{6}$ stroke.*

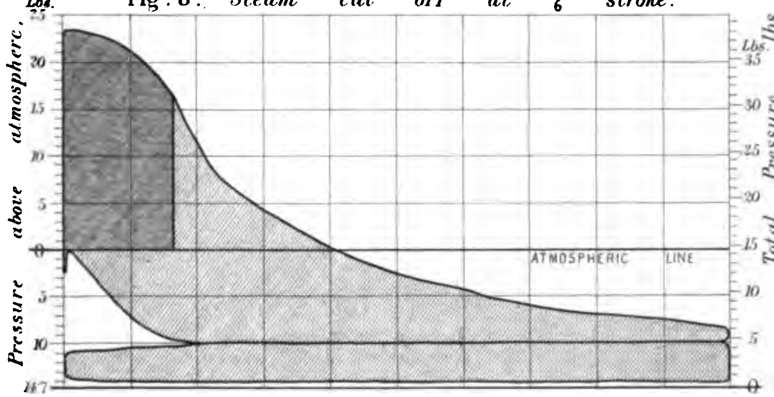
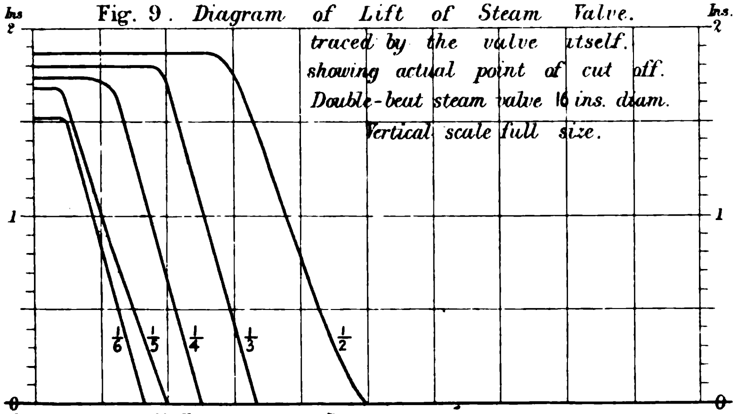


Fig. 9. *Diagram of Lift of Steam Valve.*
traced by the valve itself.
showing actual point of cut off.
Double-beat steam valve 16 ins. diam.
Vertical scale full size.



(Proceedings Inst. M. E. 1862. Page 147.)

Pressure above atmosphere, lbs. per square inch.

Total Pressure, lbs. per square inch.

Fig. 10. *Indicator Diagram from 80 inch cylinder.*
Total Load equal to 14·38 lbs. per square inch on the piston.
Steam cut off at $\frac{1}{3}$ stroke. Actual length of stroke 9 ft. 9 ins.

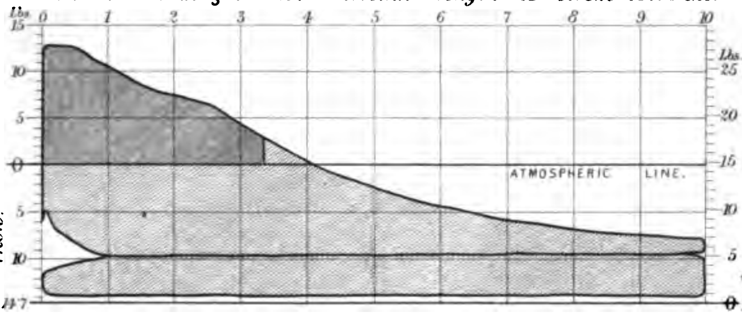


Fig. 11. *Indicator Diagram from 90 inch cylinder.*
Total Load equal to 15·58 lbs. per square inch on the piston.
Steam cut off at $\frac{1}{4}$ stroke. Actual length of stroke 10 ft. 7 ins.

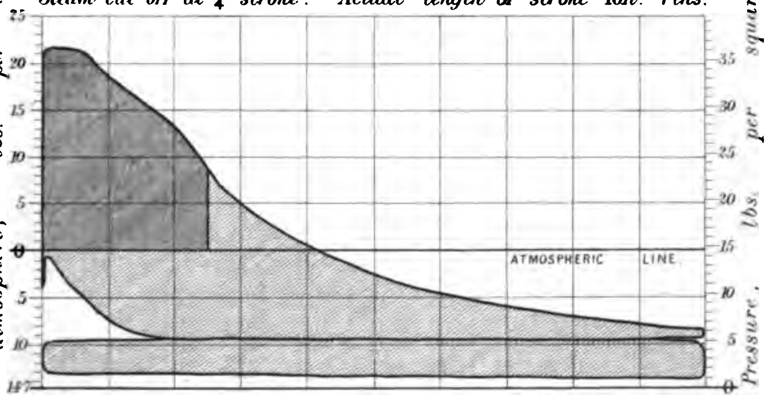


Fig. 12. *Indicator Diagram from 100 inch cylinder.*
Total Load equal to 16·58 lbs. per square inch on the piston.
Steam cut off at $\frac{1}{4}$ stroke. Actual length of stroke 11 ft.

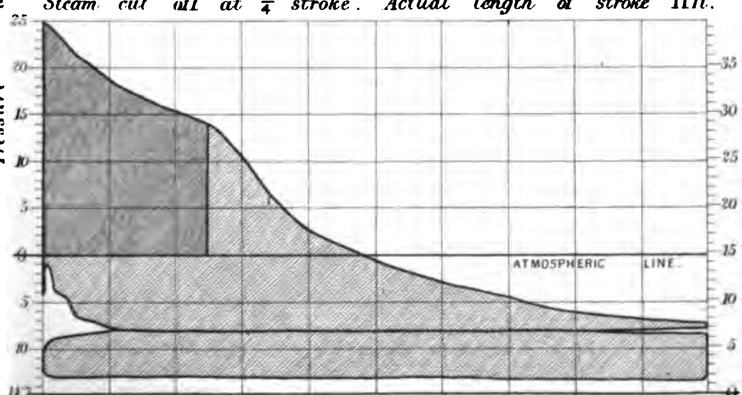


Plate 46.

ROPE MANUFACTURE.

Hand Spinning Machine for Hemp Rope.

Fig. 1. Front Elevation.

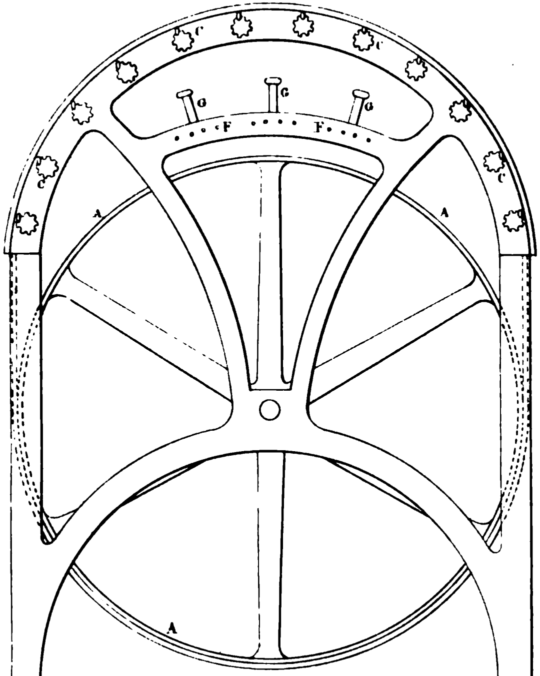


Fig. 2. Side Elevation.

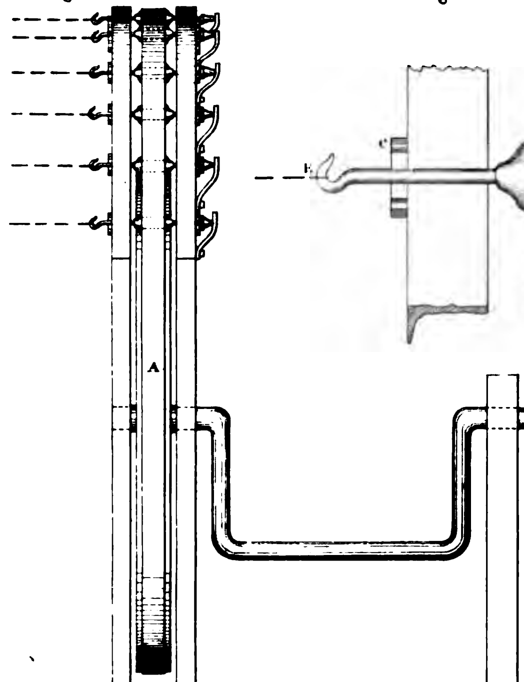
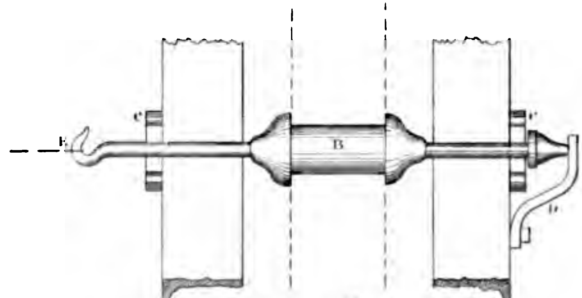
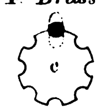


Fig. 3. Hook and Driving Roller, enlarged.



Scale 1/6th

Fig. 4. Brass Bearing.



Scale 1/6th

(Proceedings Inst. M.E. 1862. Page 170) Scale 1/24th 0 10 20 30 40 50 60 70 80 90 100 Inches

ROPE MANUFACTURE.

Winding Machine
for winding the hemp yarns
upon bobbins.

Fig. 5. Half Front Elevation.

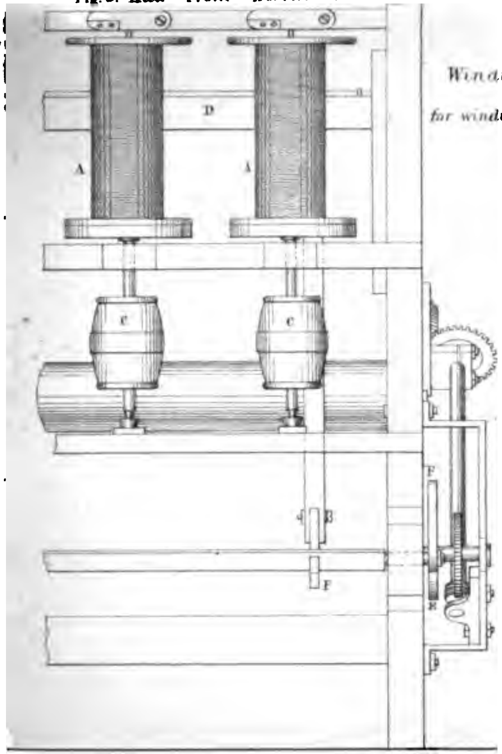
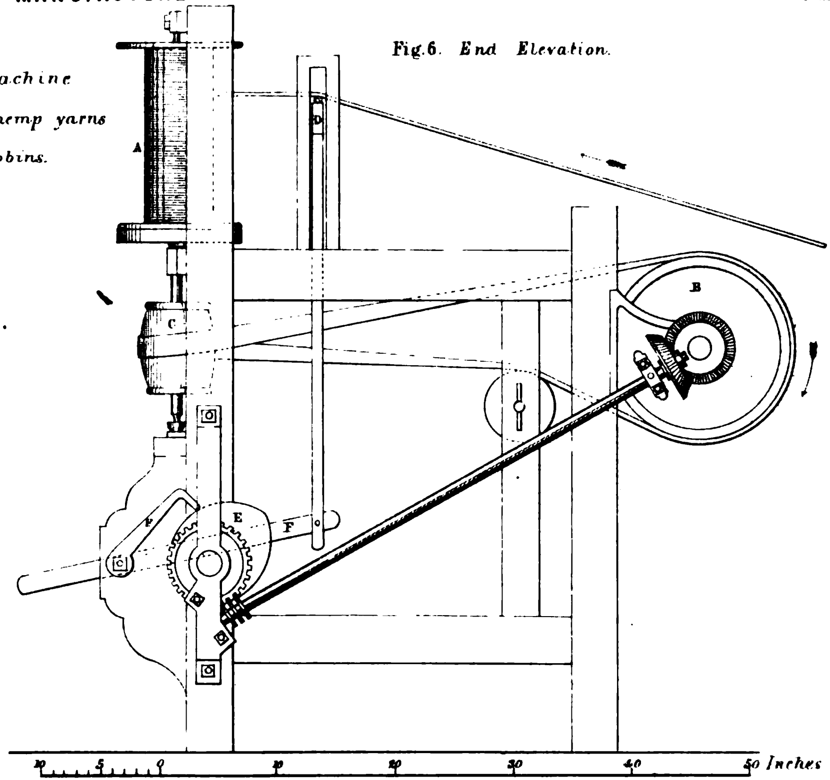
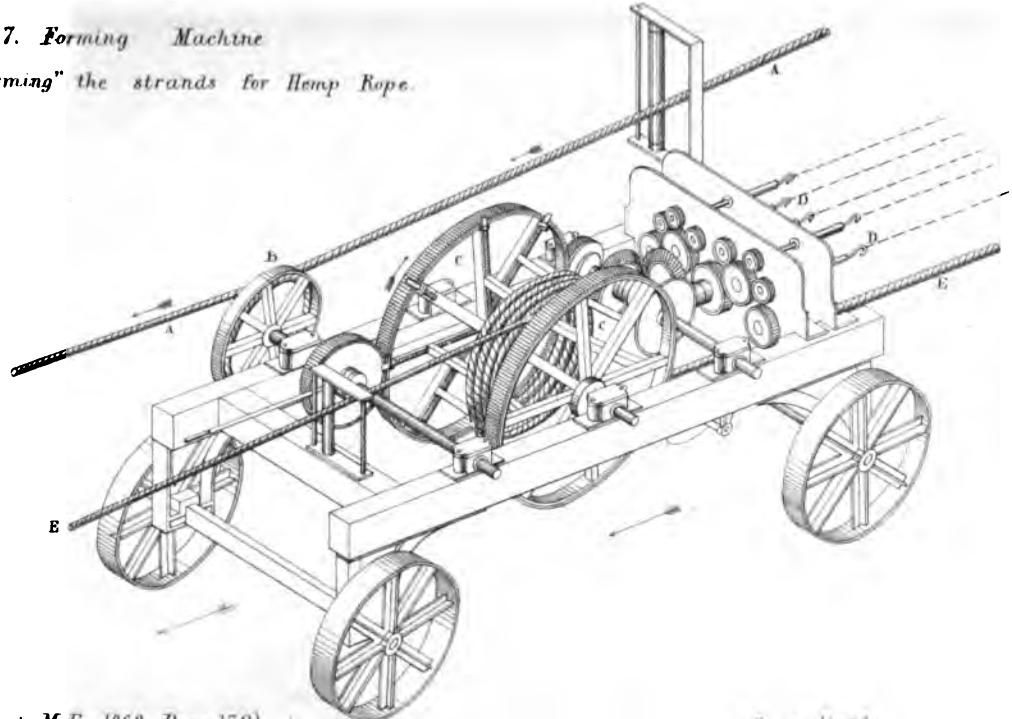


Fig. 6. End Elevation.



(Proceedings Inst. M. E. 1862 Page 170.) Scale 1/16th

Fig. 7. *Forming Machine for "forming" the strands for Hemp Rope.*

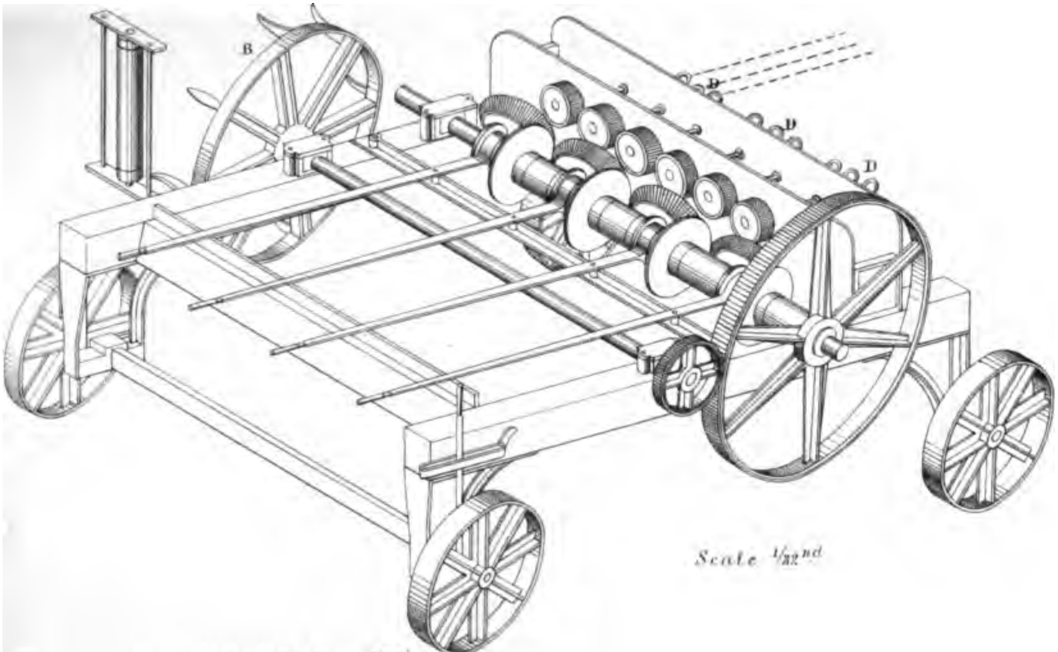


(Proceedings Inst. M.E. 1862. Page 170)

Scale 1/32nd

ROPE MANUFACTURE.

Fig. 8. *Upper End Laying Machine for "laying" the strands of Hemp Rope*



Scale 1/32nd

Laying Top.

Fig. 9. *End View.*

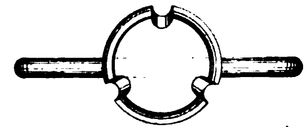
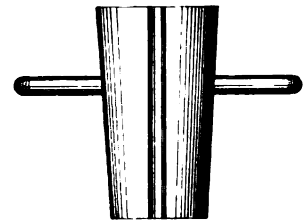


Fig. 10. *Plan.*

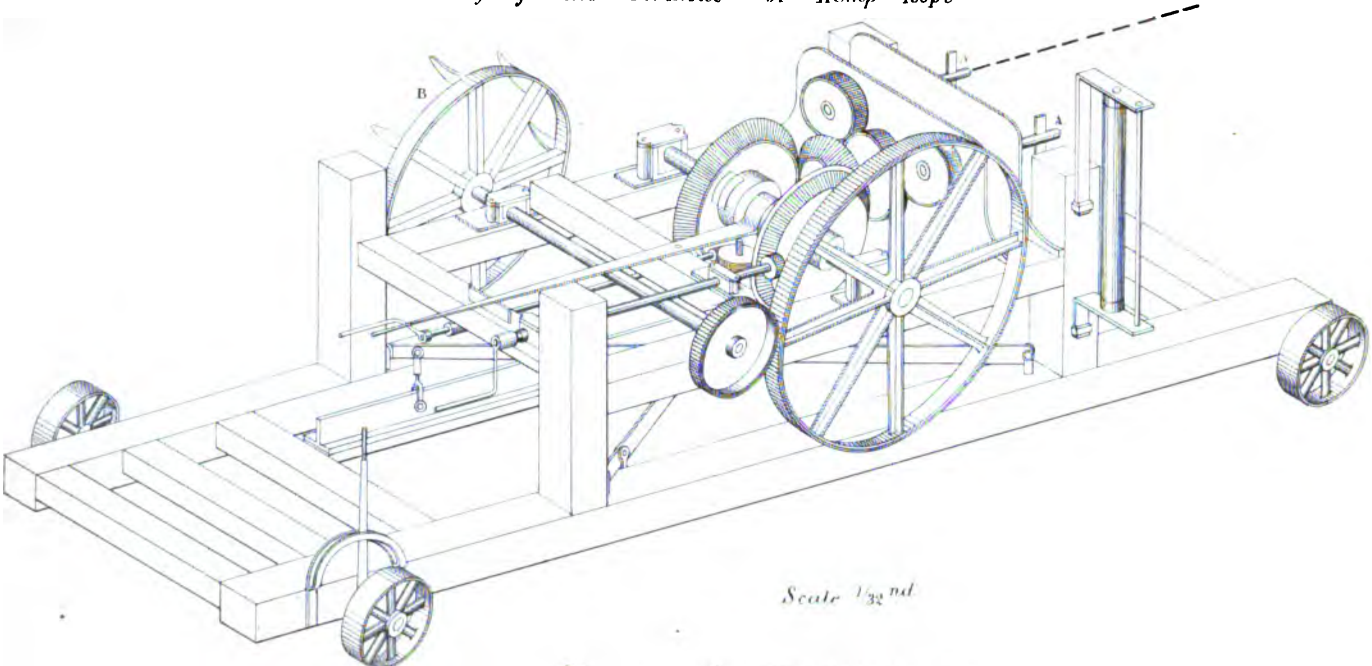


Scale 1/16th

(Proceedings Inst. M.E 1862. Page 170)

ROPE MANUFACTURE.

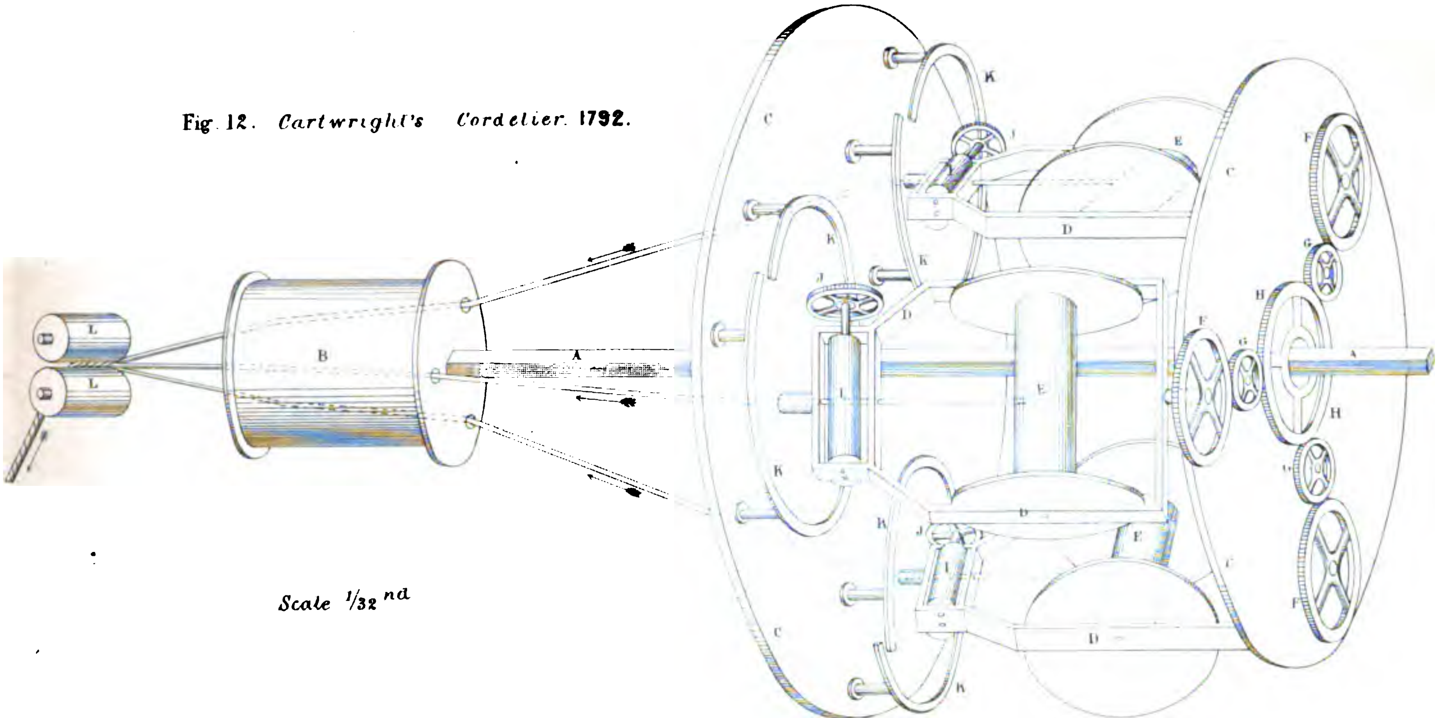
Fig. 11. *Lower End Laying Machine for "laying" the strands of Hemp Rope*



Scale 1/32nd

(Proceedings Inst. M. E. 1862. Page 170)

Fig. 12. *Cartwright's Cordelier.* 1792.



Scale 1/32nd

ROPE MANUFACTURE.

Spinning Machine for spinning hemp sliver into yarn.

Fig. 13. *Front Elevation.*

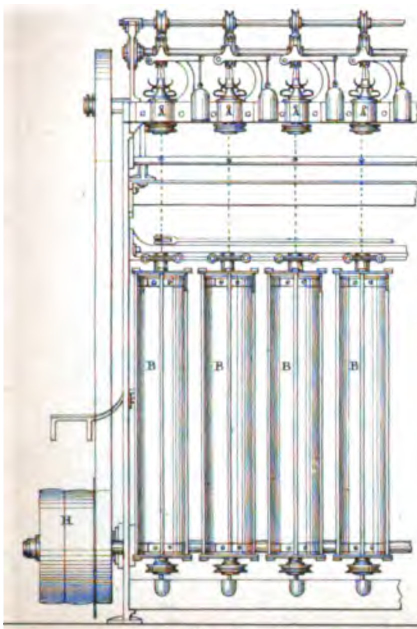
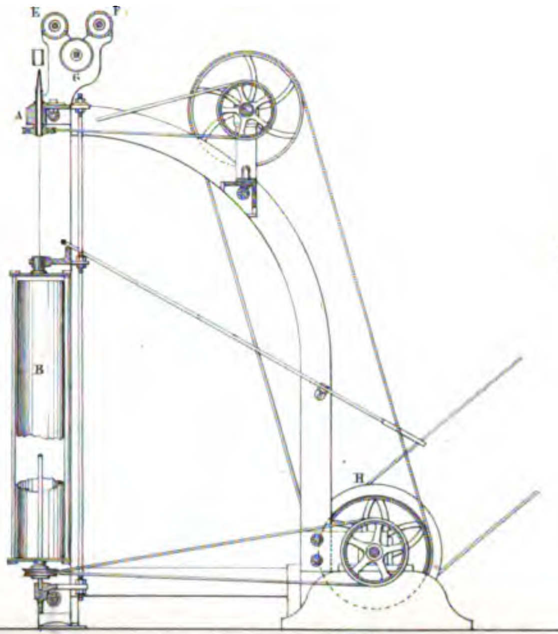


Fig. 14. *Transverse Section.*



Scale 1/24th Ins. 12 6 0 1 2 3 4 5 Feet

Fig. 15. *Detail of Spinning Tube and Compressing Jaws.*

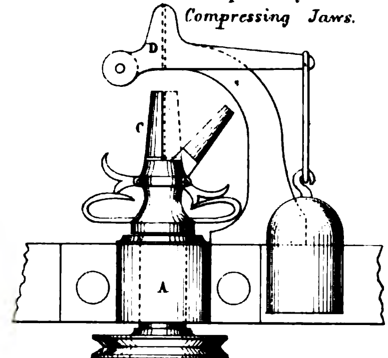


Fig. 16. *Plan of Clip.*

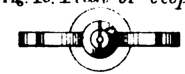
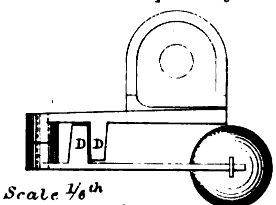


Fig. 17. *Plan of Compressing Jaws.*

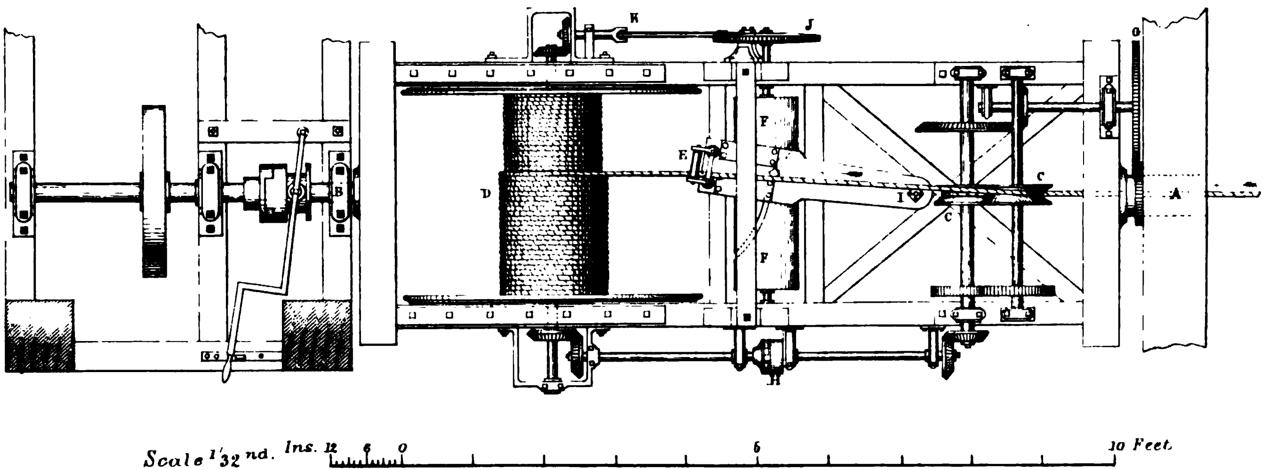


Scale 1/6th 0 5 10 Inches.

ROPE MANUFACTURE.

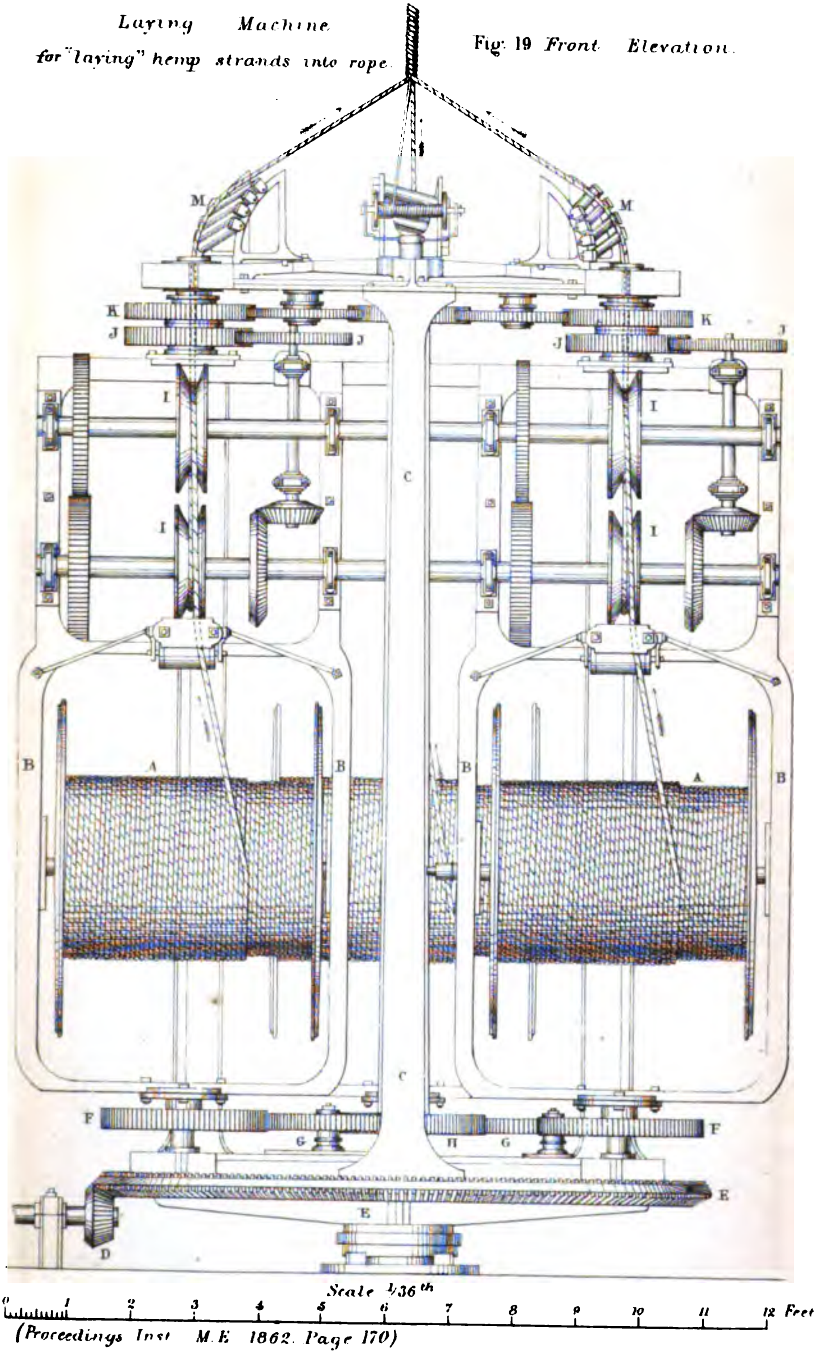
Fig. 18. *Plan of "Registering" Machine*

for twisting hemp yarns into a strand and winding the strand on a drum.



Laying Machine
for "laying" hemp strands into rope.

Fig: 19 Front Elevation.



(Proceedings Inst M.E. 1862. Page 170)

ROPE MANUFACTURE.

Laying Machine for "laying" hemp strands into rope.

Fig. 20.

Plan at top

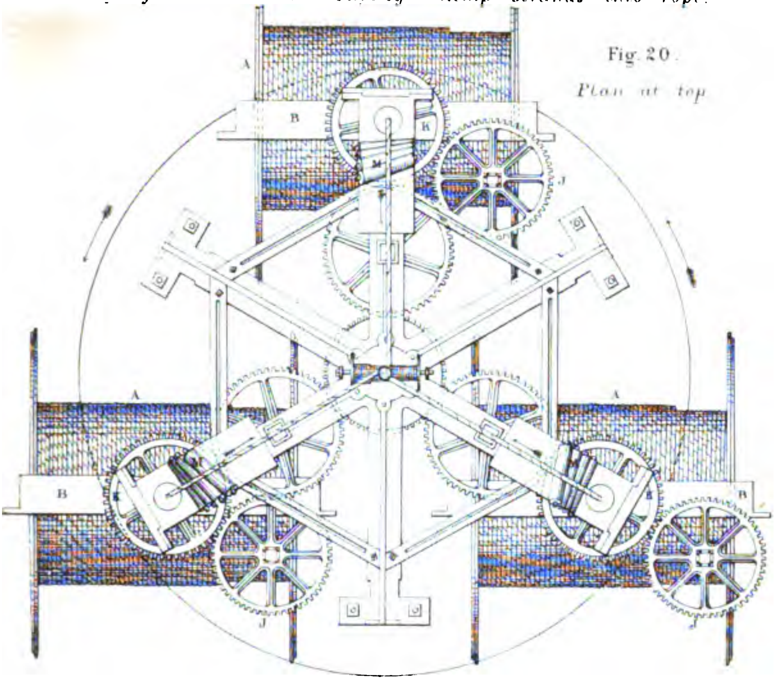
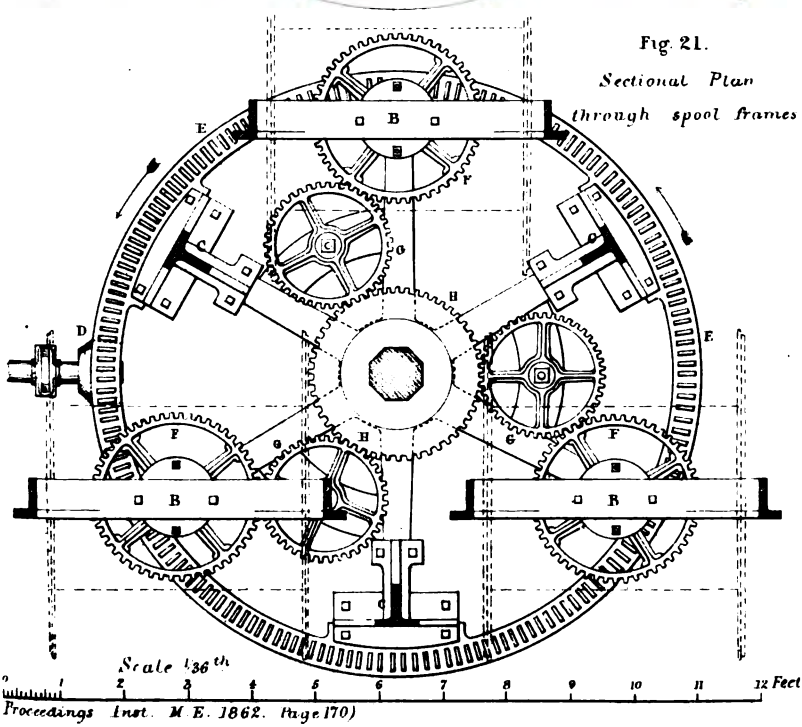


Fig. 21.

Sectional Plan through spool frames.



(Proceedings Inst. M. E. 1862. Page 170)

ROPE MANUFACTURE.

Laying Machine for "laying" hemp strands into rope.

Fig. 22
Side Elevation of Spool Frame enlarged.

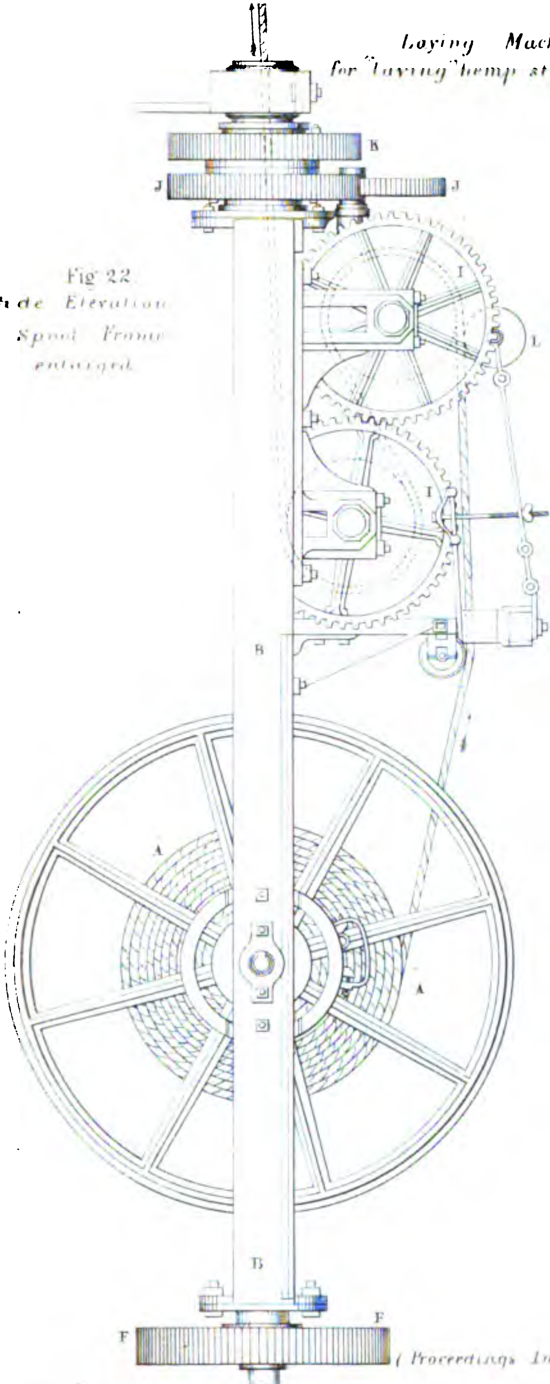
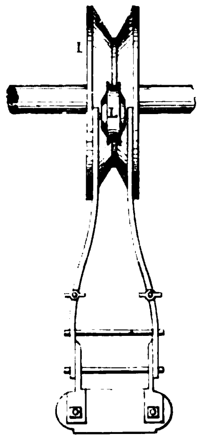


Fig. 23.
Tightening Pulley.



(Proceedings Inst M E 1862 Page 170)

Scale 1/24th Inst 12 6 0 1 2 3 4 5 Feet

ROPE MANUFACTURE.

Plate 57.

Wire Ropes.

Fig. 24. *Freiburg Suspension Bridge Cable.* 1835.
Scale 1/24th.

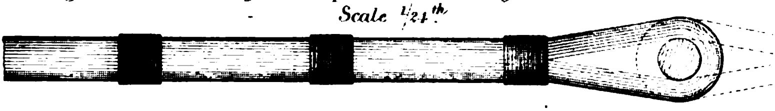


Fig. 25. *"Selvagee" Wire Rope.* 1835.

Fig. 26

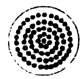


Fig. 27. *"Formed" Wire Rope.* 1837.

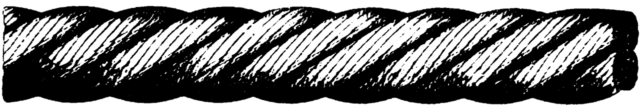


Fig. 28.

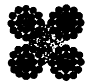


Fig. 29. *First Flat Wire Rope.* 1836.

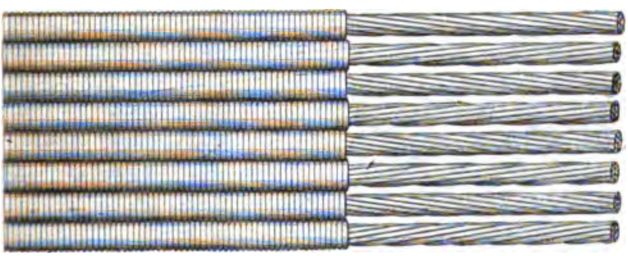


Fig. 30.

Fig. 31. *Second Flat Wire Rope.* 1837.

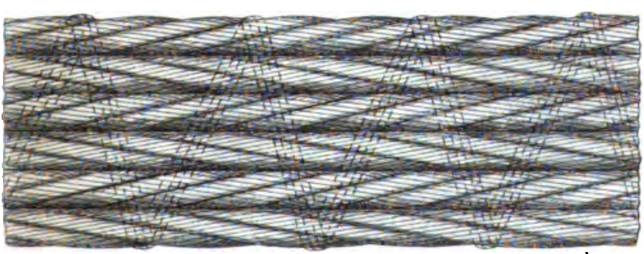


Fig. 32.

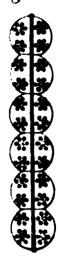


Fig. 33. *"Laid" Wire Rope.* 1838.

Fig. 34.

(Proceedings Inst. M.E. 1862. Page 170.) *Scale 1/3rd full size.*

ROPE MANUFACTURE.

Fig. 35.

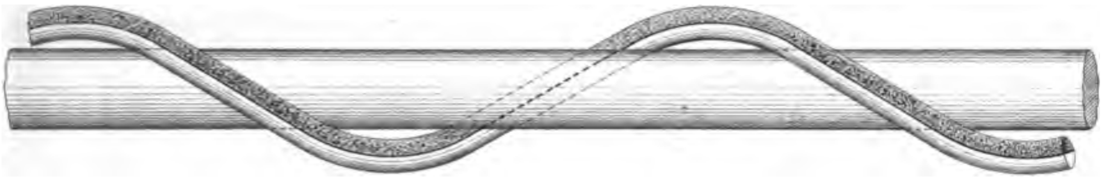


Fig. 36.

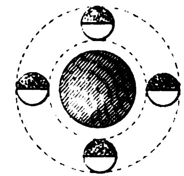


Fig. 37.

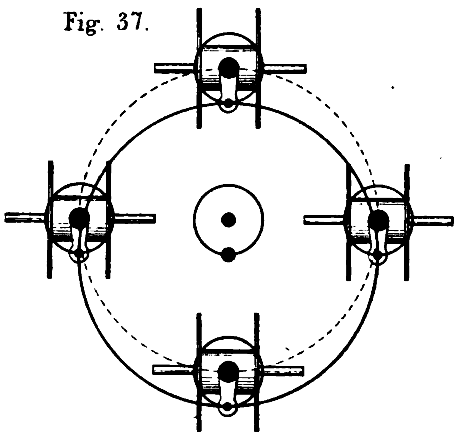


Fig. 38.

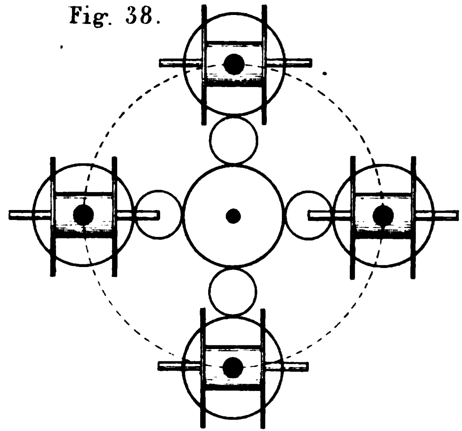
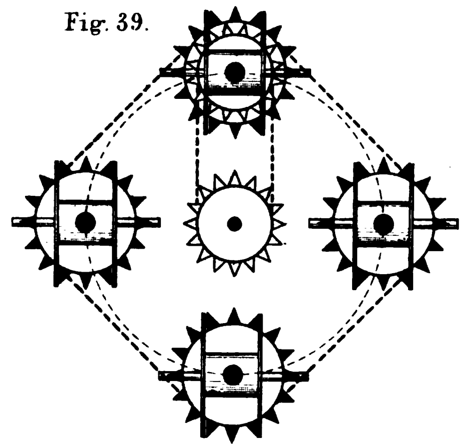


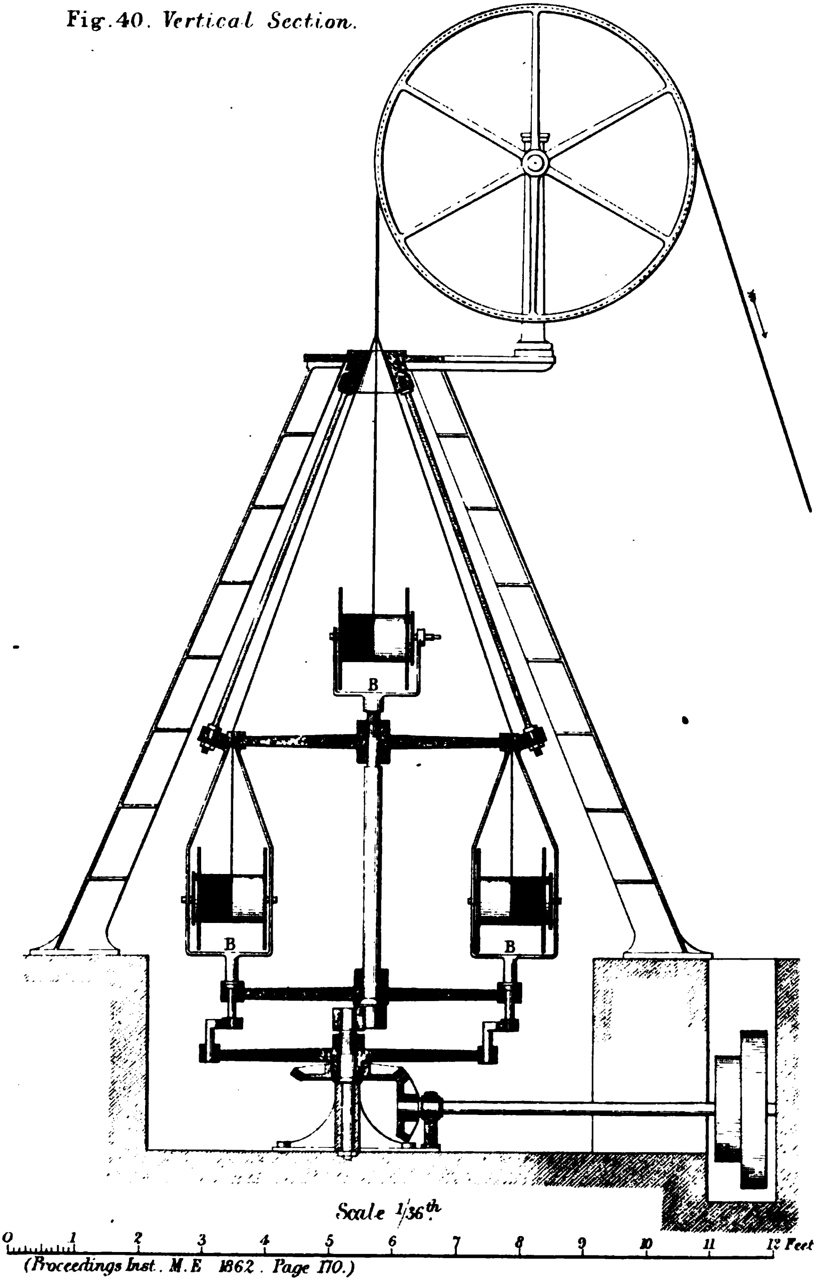
Fig. 39.



(Proceedings Inst. M.E. 1862. Page 170.)

Huddart's Wire Rope Machine.

Fig. 40. Vertical Section.

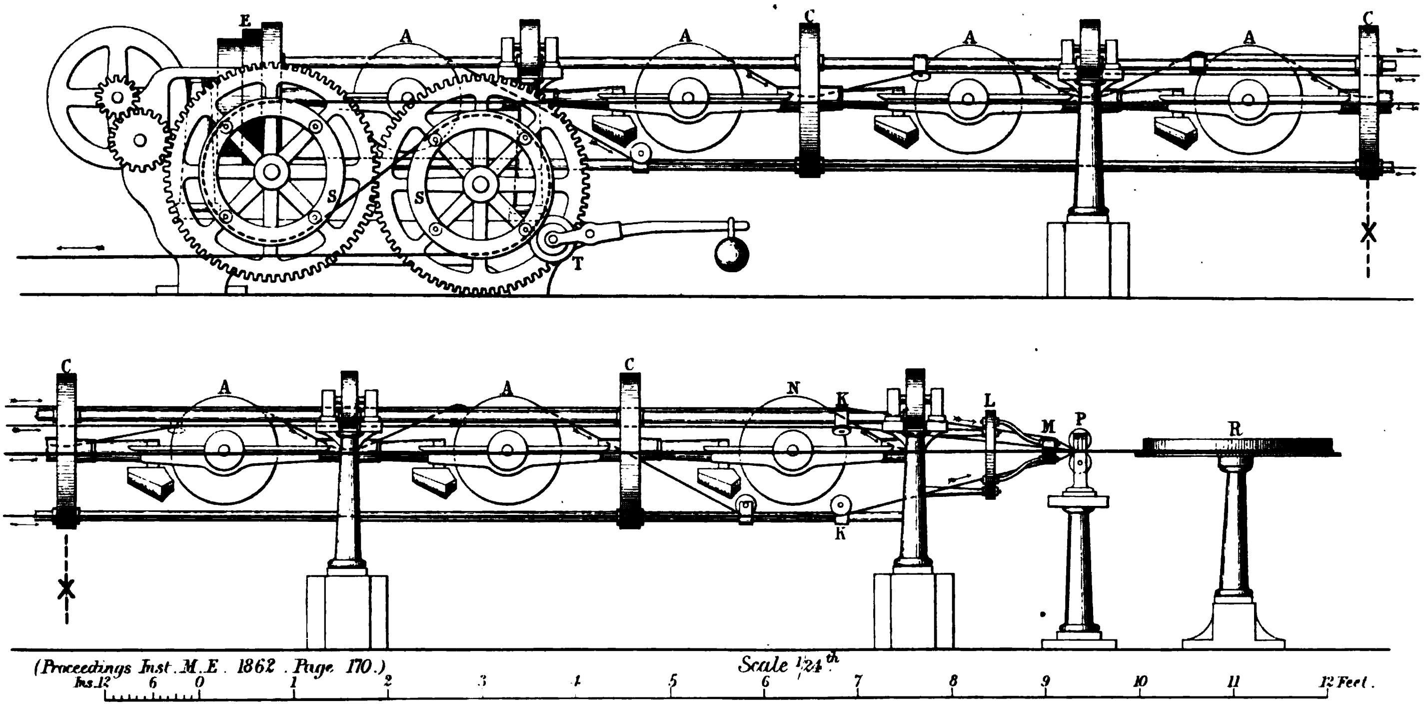


(Proceedings Inst. M. E 1862. Page 170.)

ROPE MANUFACTURE.

Plate 60.

Smith's Wire Rope Machine. Fig. 41. Side Elevation.

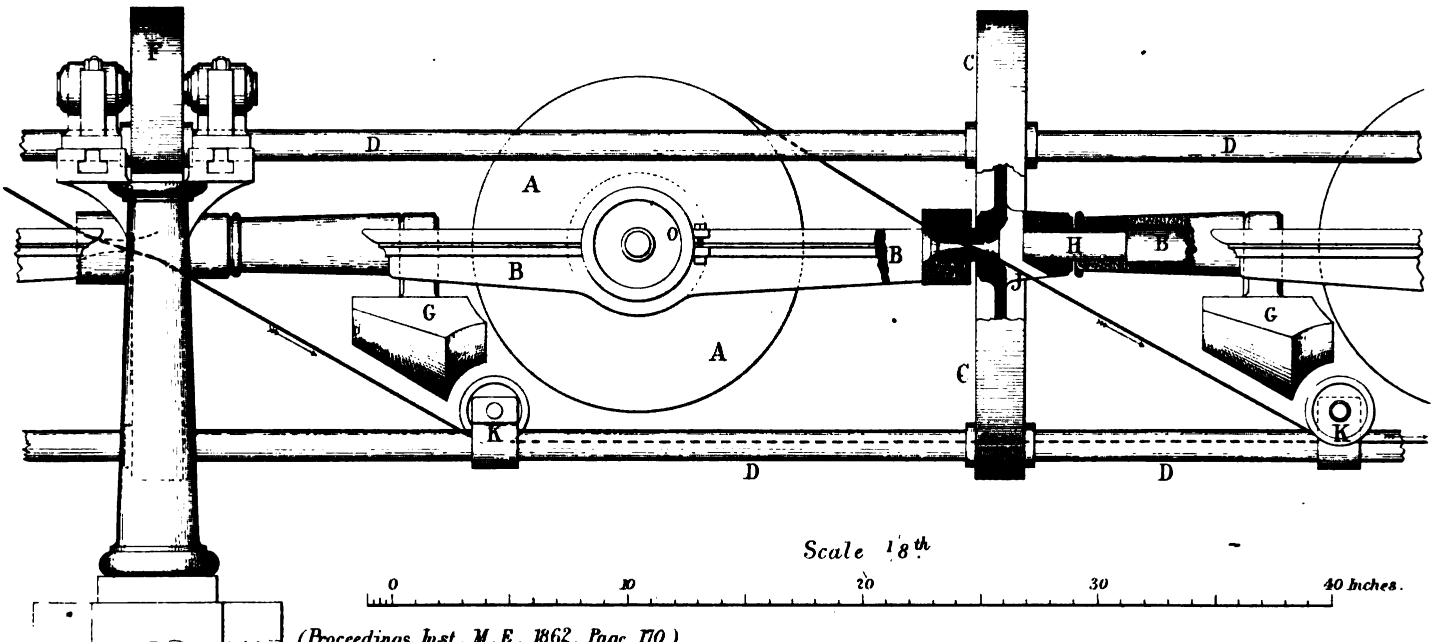


(Proceedings Inst. M. E. 1862. Page 170.)

ROPE MANUFACTURE.

Smith's Wire Rope Machine.

Fig. 42. *Side Elevation, enlarged.*



(Proceedings Inst. M.E. 1862. Page 170.)

Smith's Wire Rope Machine.

Fig. 43. *Transverse Section.*

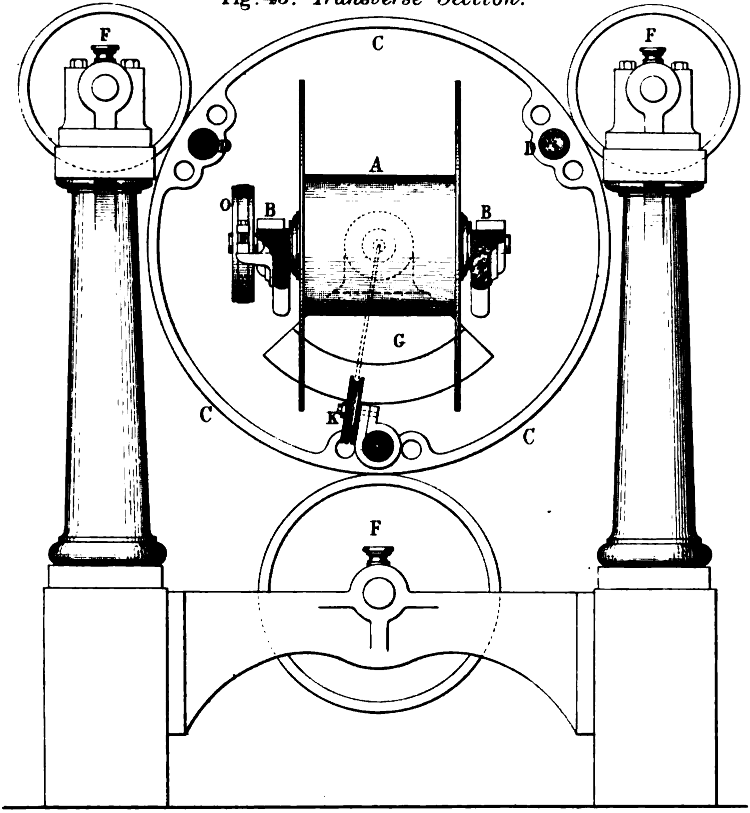
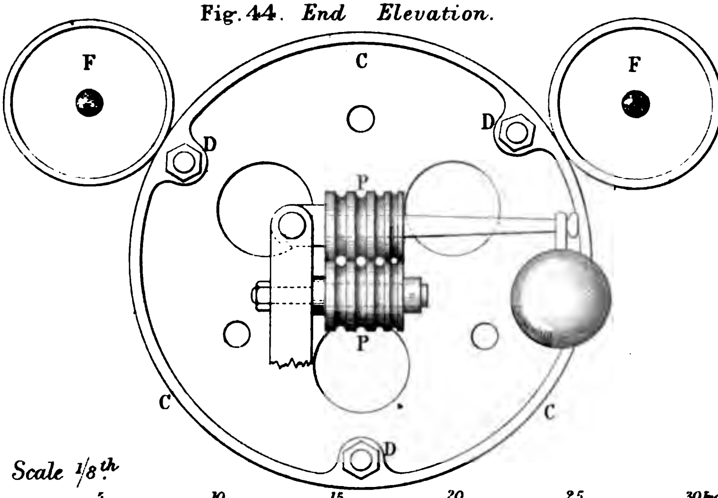


Fig. 44. *End Elevation.*



Scale 1/8th.

0 5 10 15 20 25 30 Inches.

Malta and Alexandria. 1861.

Fig. 1. *Main Cable.*

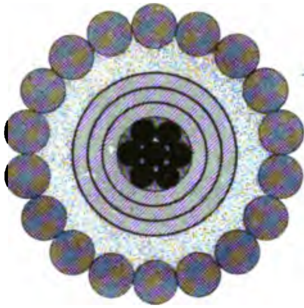


Fig. 2. *Shore End.*

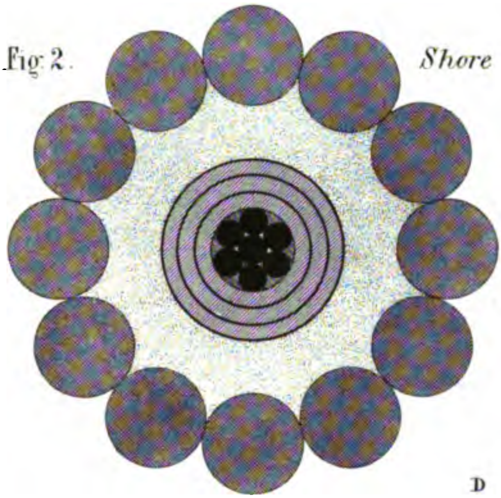
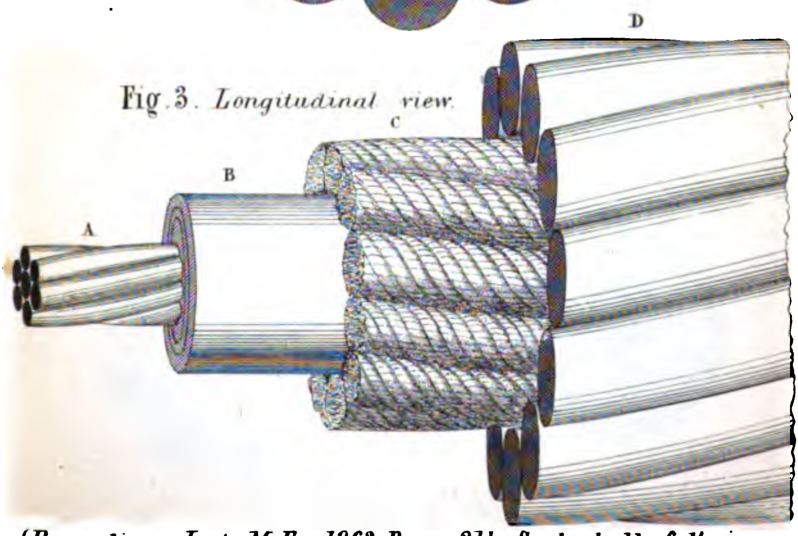


Fig. 3. *Longitudinal view.*



(Proceedings Inst. M.E. 1862 Page 211) Scale double full size.

Fig. 4. *Spezzia and Corsica* 1854.

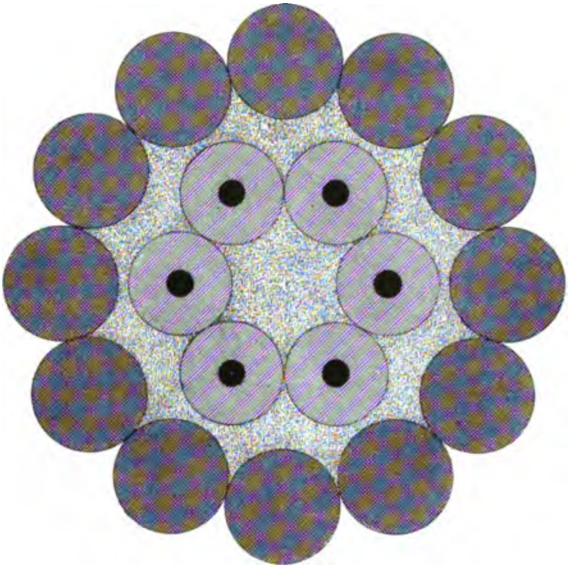


Fig. 5. *Varna and Balaclava.* 1855.

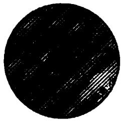


Fig. 6. *Atlantic.* 1857.

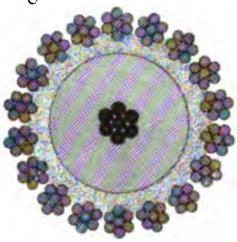


Fig. 8. *Toulon and Algiers.* 1860.

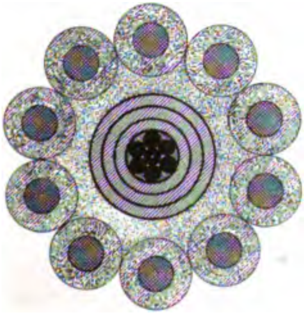
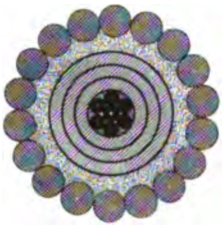


Fig. 7. *Red Sea.* 1859.



(Proceedings Inst. M.E. 1862. Page 211.) Scale double full size.

SUBMARINE TELEGRAPH CABLES.

England and Holland. 1862.

Plate 65.

Fig. 9 *Main Cable.*

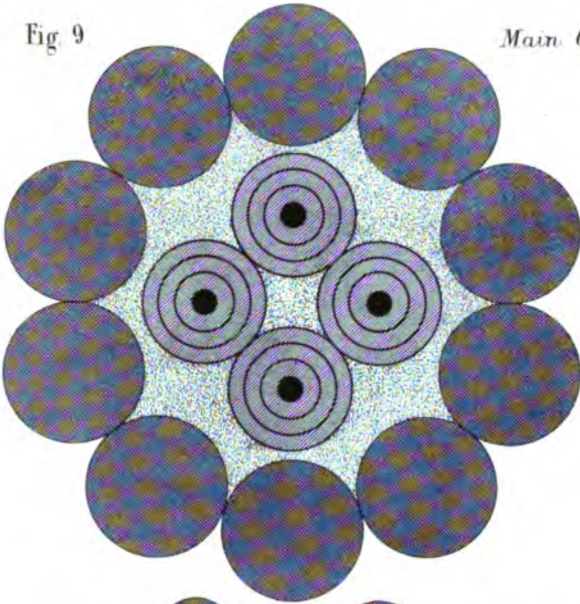
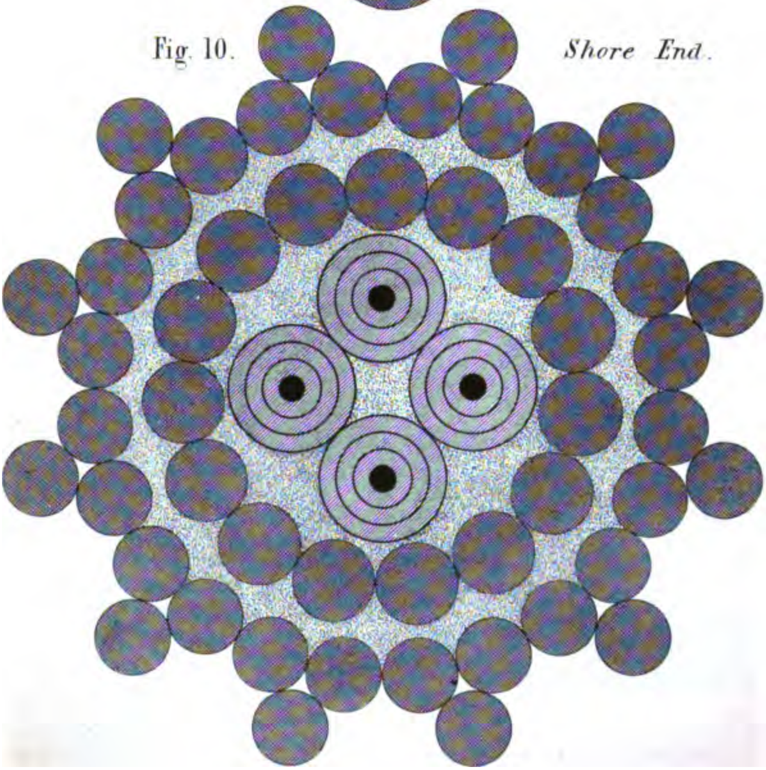


Fig. 10. *Shore End.*



(Proceedings Inst M.E. 1862. Page 211) Scale double full size.

Fig. 11. *Isle of Man.* 1859.

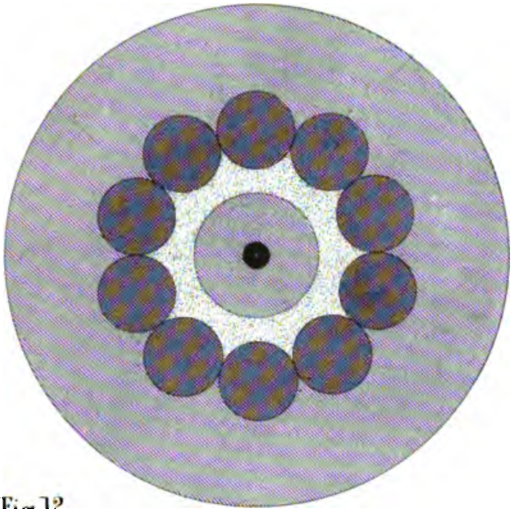


Fig. 12.
Chatterton's Cable. 1862.

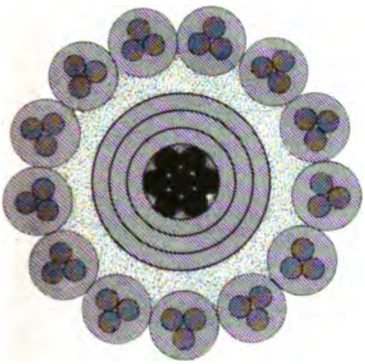


Fig. 13.
Allan's Cable. 1862.

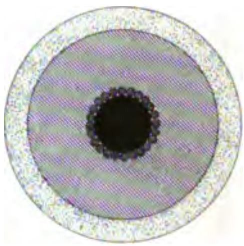
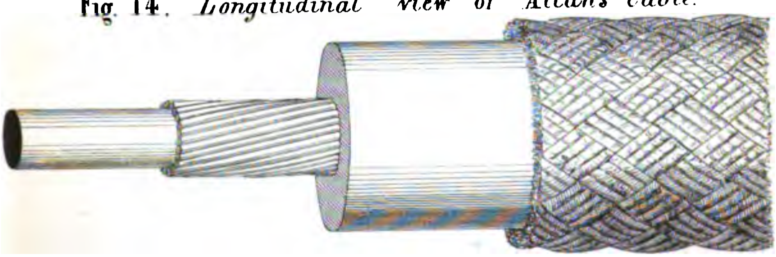


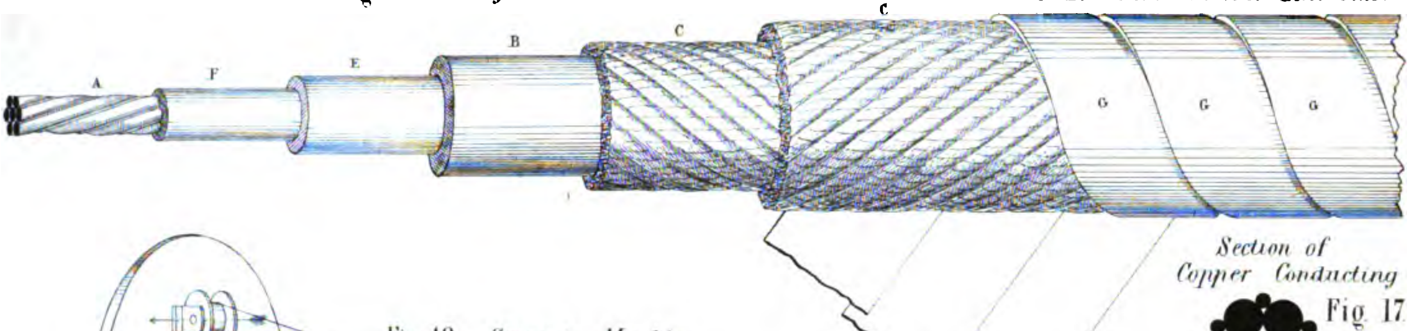
Fig. 14. *Longitudinal view of Allan's Cable.*



(Proceedings Inst. M.E. 1862 Page 211) Scale double full size.

SUBMARINE TELEGRAPH CABLES.

Fig. 15. *Longitudinal view of Siemens' Cable.* **1862.** *Scale double full size.*

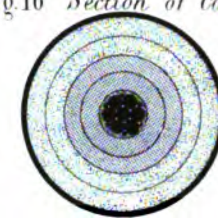


Section of Copper Conducting Core.

Fig. 17.

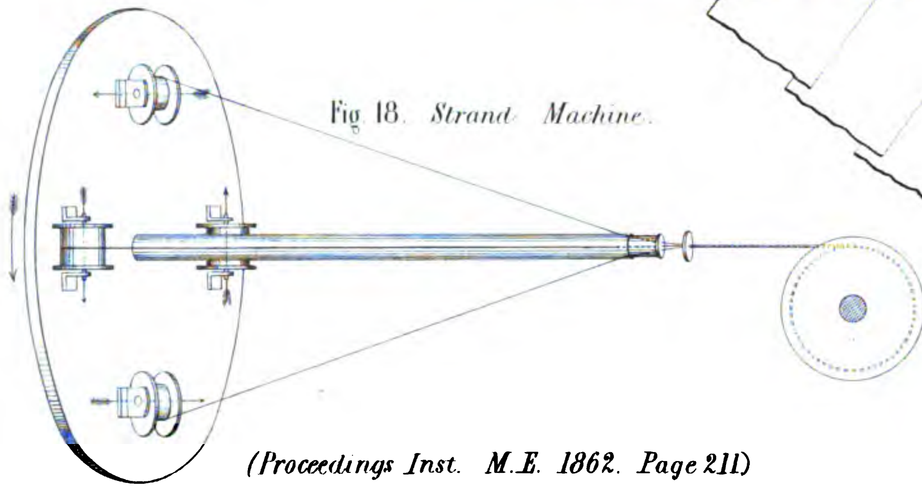
Scale six times full size.

Fig. 16. *Section of Cable.*



Scale double full size.

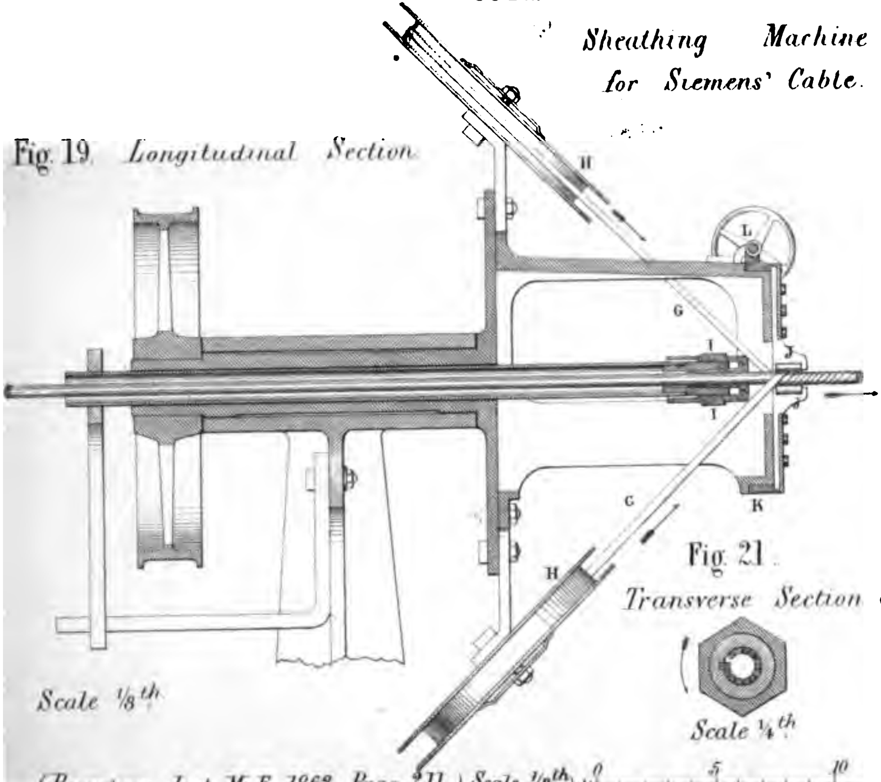
Fig. 18. *Strand Machine.*



(Proceedings Inst. M.E. 1862. Page 211)

Sheathing Machine for Siemens' Cable.

Fig. 19. Longitudinal Section



Scale 1/8th

Fig. 20. End Elevation.

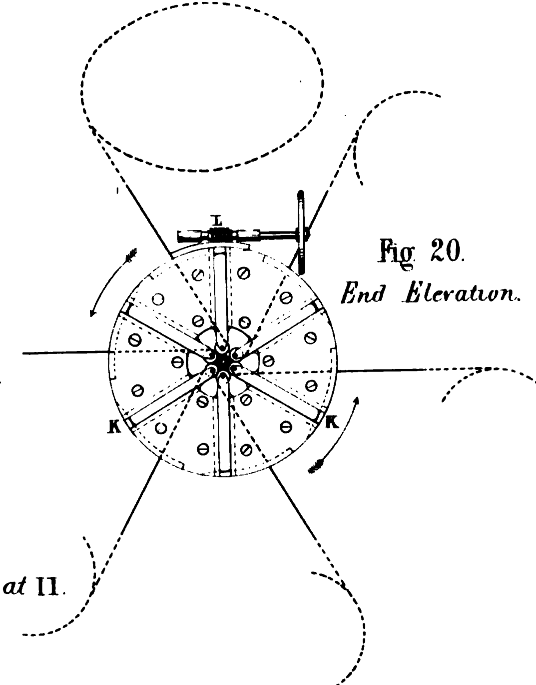


Fig. 21. Transverse Section at II.

Scale 1/4th

(Proceedings Inst. M. E. 1862. Page 211.) Scale 1/8th 0 5 10 20 30 Inches.

Theoretical Diagrams of Comparative Initial Blow and Motive Force throughout stroke, in Single and Double Cylinder Engines of equal power and expanding SIX *times.*

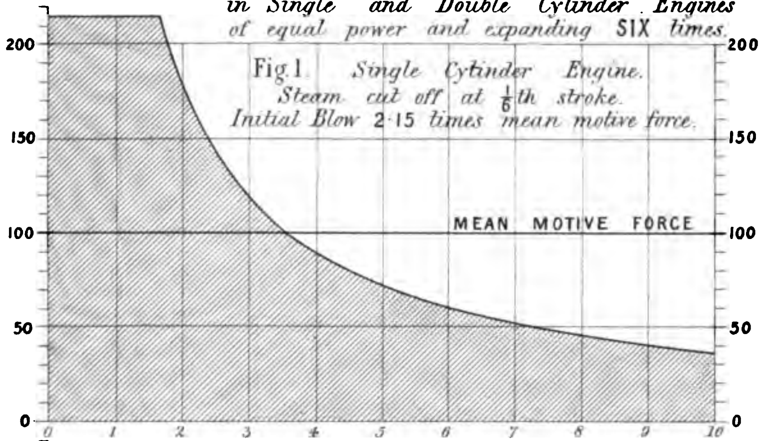


Fig. 1. *Single Cylinder Engine.*
Steam cut off at $\frac{1}{6}$th stroke.
Initial Blow 2·15 *times mean motive force.*

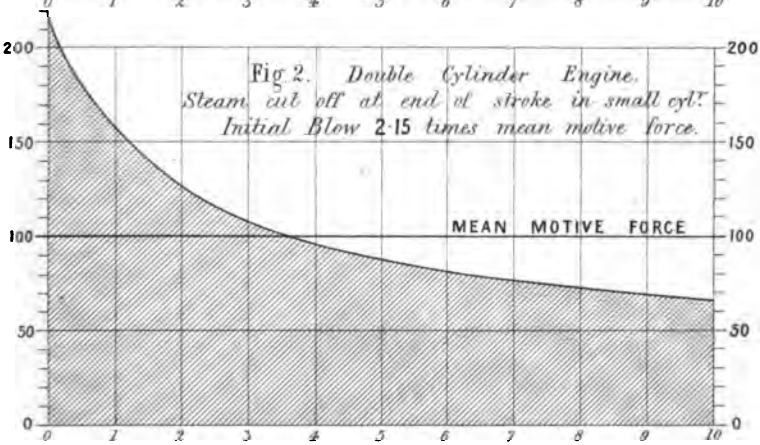


Fig. 2. *Double Cylinder Engine.*
Steam cut off at end of stroke in small cyl^r.
Initial Blow 2·15 *times mean motive force.*

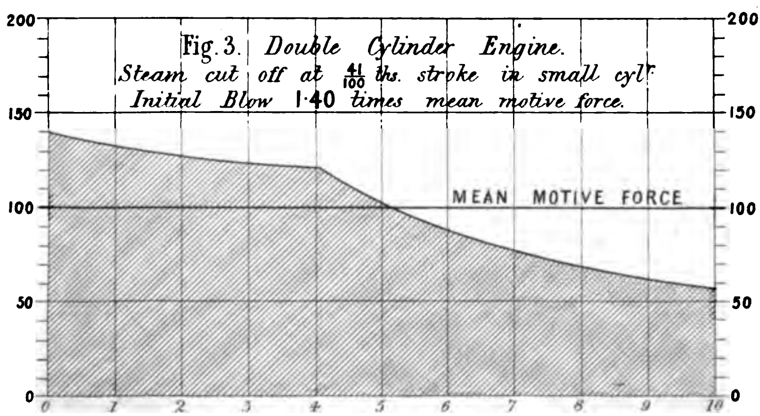
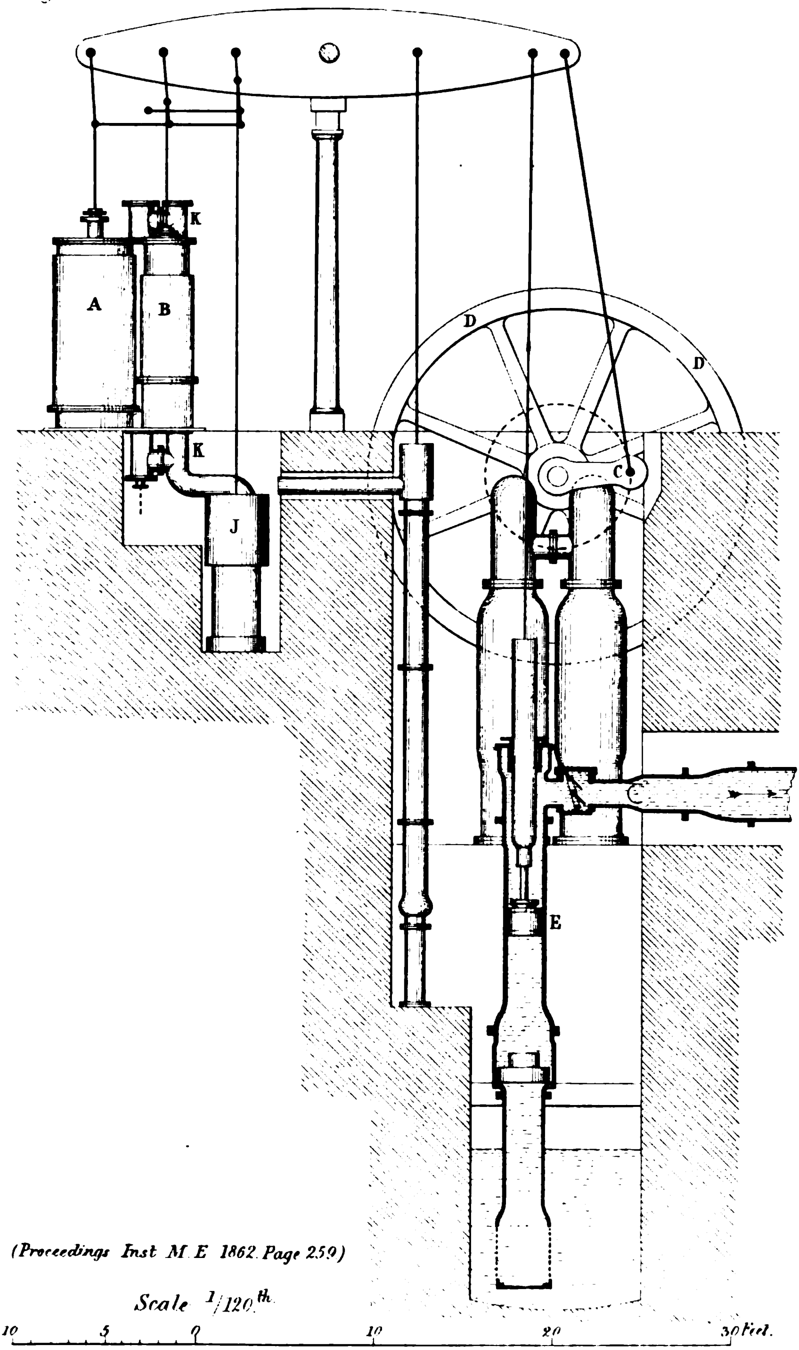


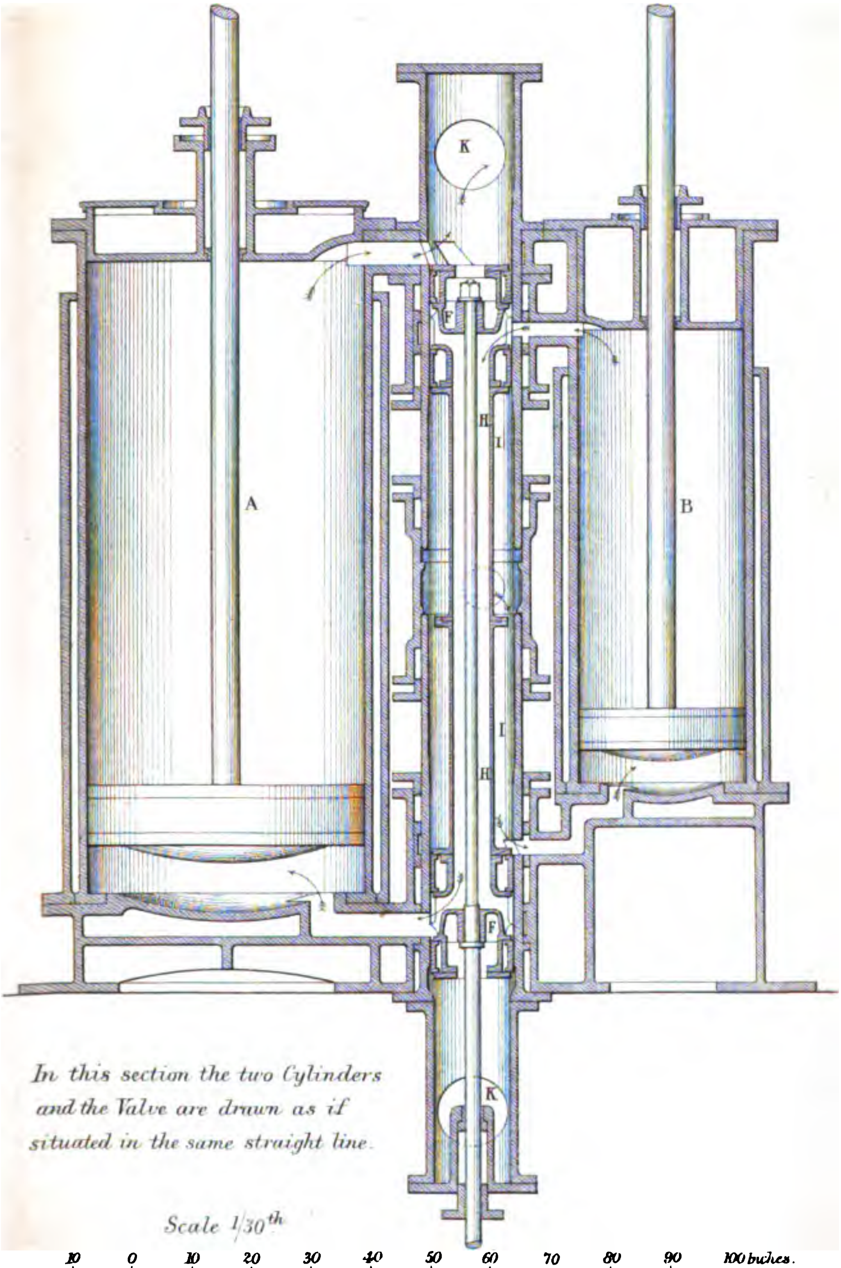
Fig. 3. *Double Cylinder Engine.*
Steam cut off at $\frac{41}{100}$ths. stroke in small cyl^r.
Initial Blow 1·40 *times mean motive force.*

Fig. 1. *Double Cylinder Pumping Engines at Lambeth Water Works.*



(Proceedings Inst M. E. 1862. Page 259)

Fig. 2. *Vertical Section of Cylinders and Valve.*



In this section the two Cylinders and the Valve are drawn as if situated in the same straight line.

Scale 1/30th

(Proceedings Inst. M.E. 1862. Page 259.)

Fig. 3. *Sectional Plan through steam port of Large cylinder.*

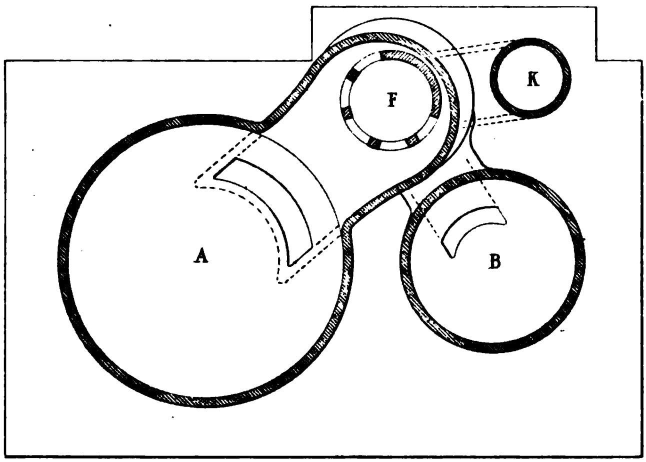
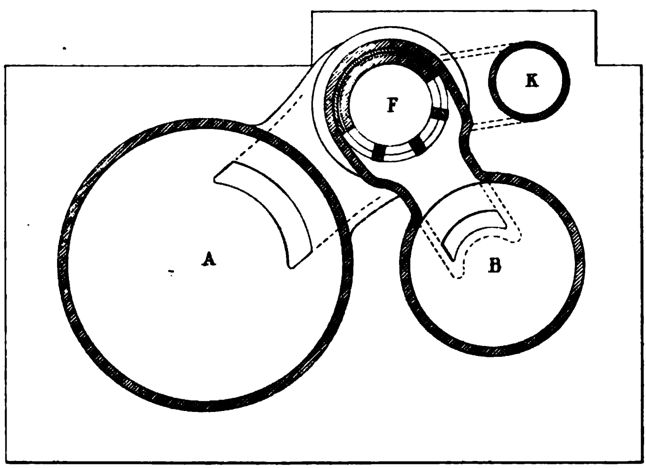
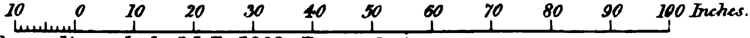


Fig. 4. *Sectional Plan through steam port of Small cylinder.*



Scale 1/30th.



(Proceedings Inst. M.E. 1862. Page 259.)

DOUBLE CYLINDER ENGINES.

Fig. 5.

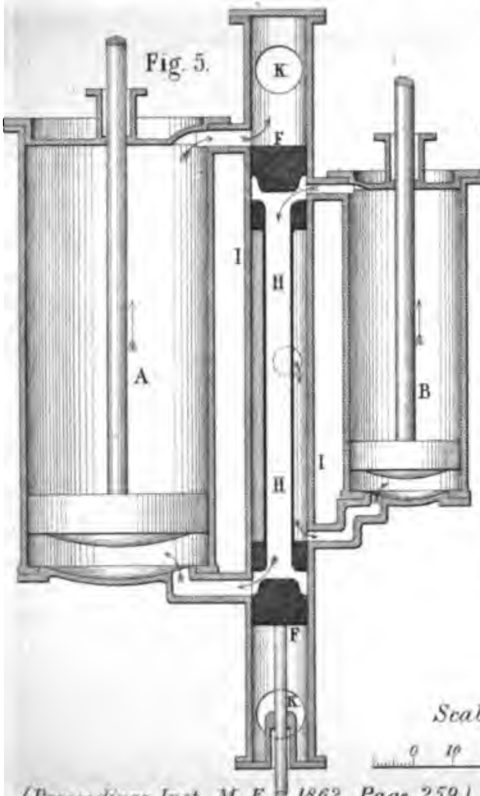
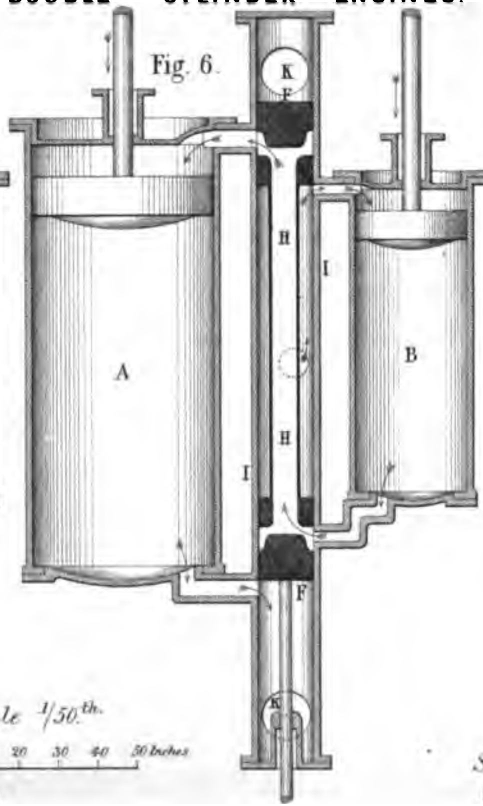


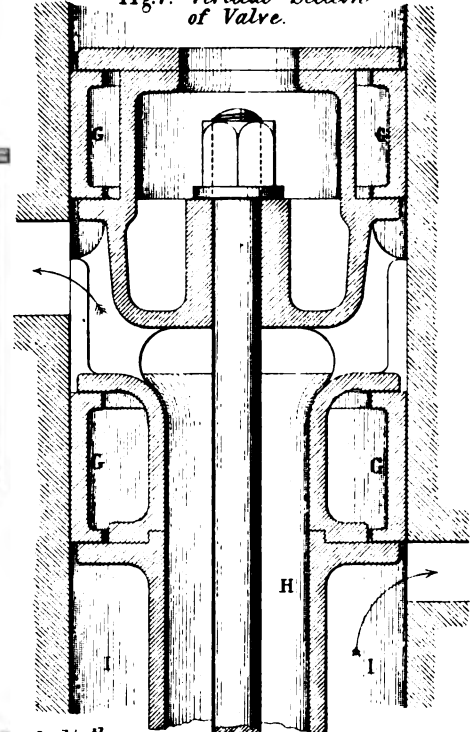
Fig. 6.



Scale 1/50th.

0 10 20 30 40 50 Inches

Fig. 7. Vertical Section of Valve.



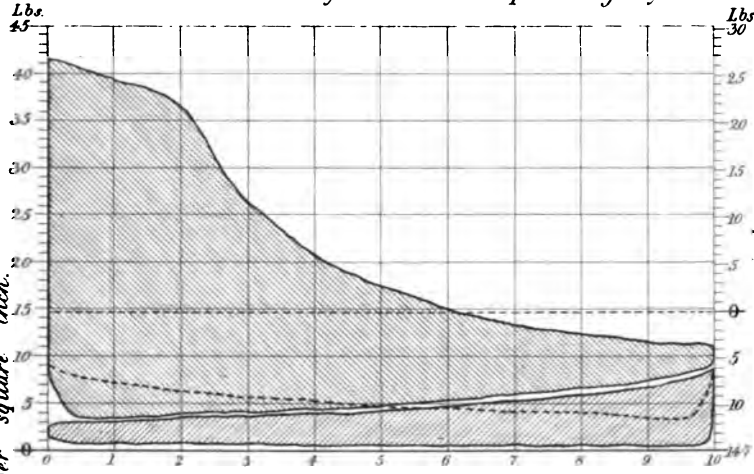
Scale 1/8th.

0 5 10 15 Inches

(Proceedings Inst. M. E. 1862. Page 259.)

Indicator Diagrams from Lambeth Water Works Engines.

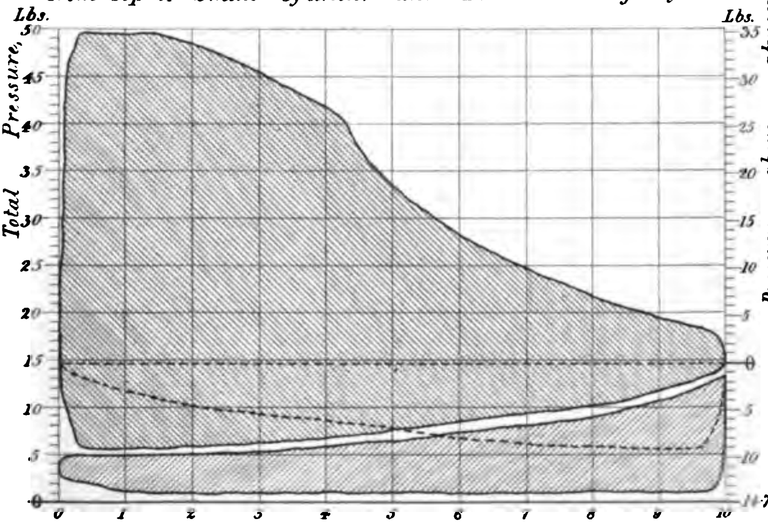
Fig. 8. *Indicator Diagrams taken simultaneously from Bottom of Small cylinder and Top of Large cylinder.*



Total Pressure, lbs. per square inch.

Pressure above atmosphere, lbs. per square inch.

Fig. 9. *Indicator Diagrams taken simultaneously from Top of Small cylinder and Bottom of Large cylinder.*



(Proceedings Inst. M.E. 1862. Page 259.)

Fig. 10. *Indicator Diagram from Top of Small cylinder, taken simultaneously with Fig. 8.*

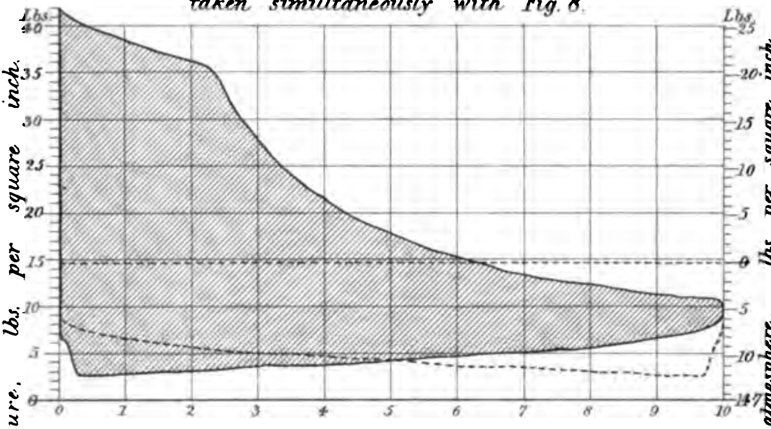


Fig. 11. *Indicator Diagram from Top of Large cylinder, taken simultaneously with Fig. 9.*

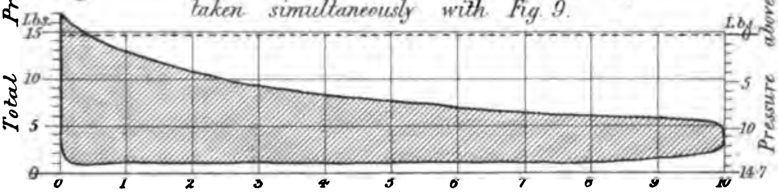
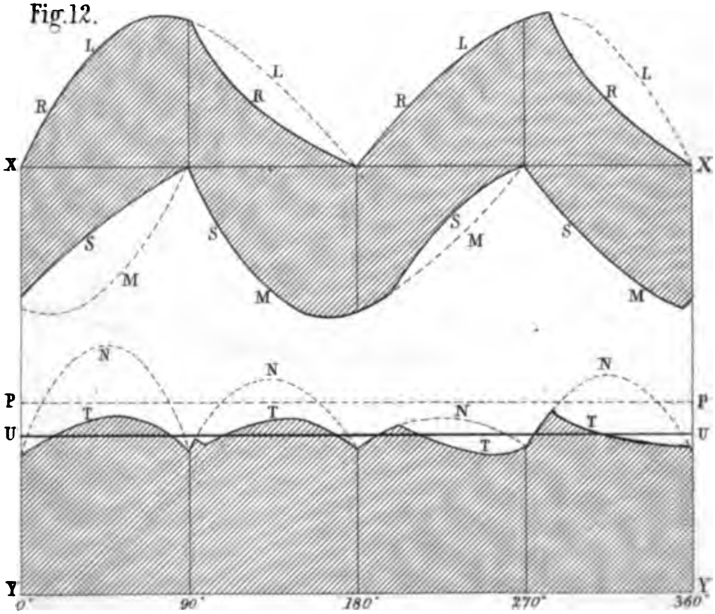


Fig. 12.

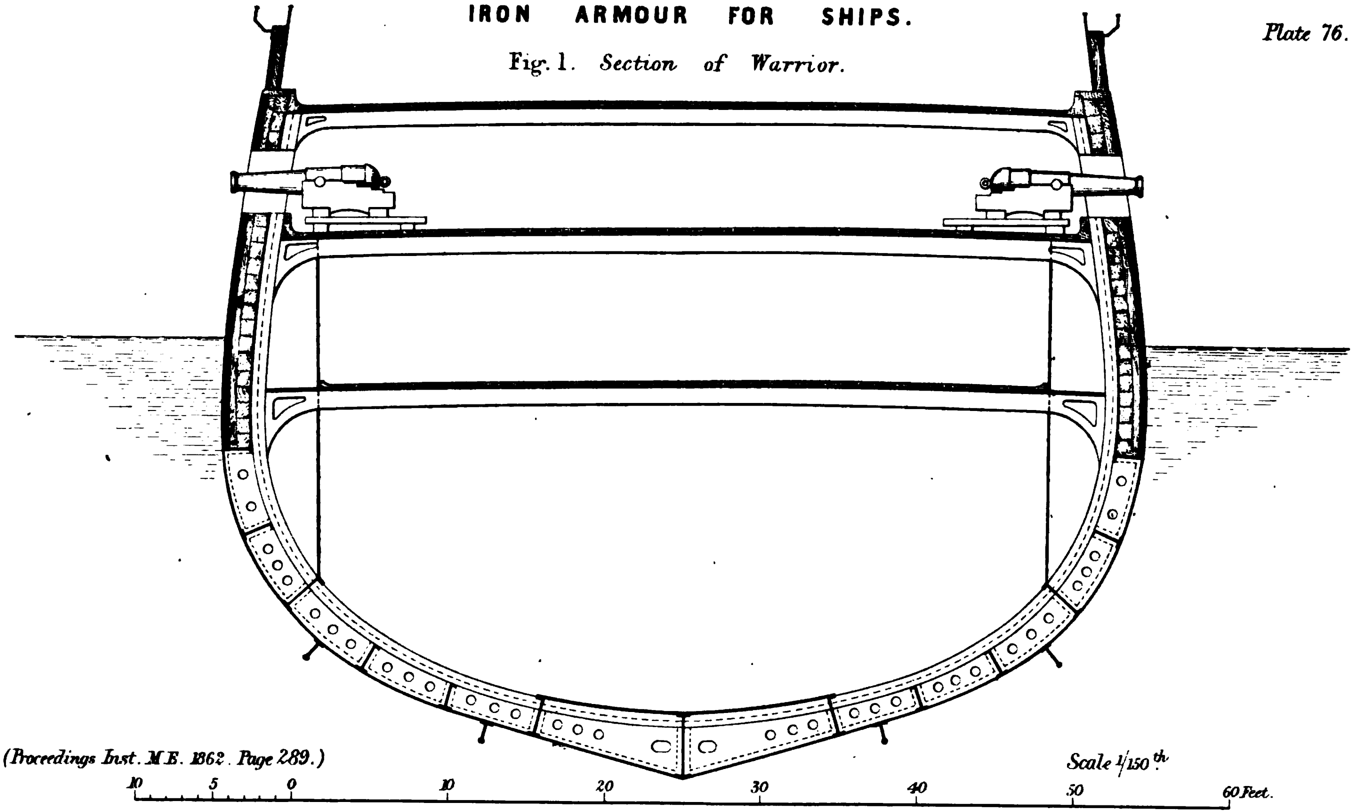


(Proceedings Inst. M.E. 1862. Page 259.)

Plate 76.

IRON ARMOUR FOR SHIPS.

Fig. 1. *Section of Warrior.*



(Proceedings Inst. M.E. 1862. Page 289.)

IRON ARMOUR FOR SHIPS.

Plate 77.

Fig. 2. *La Gloire.*

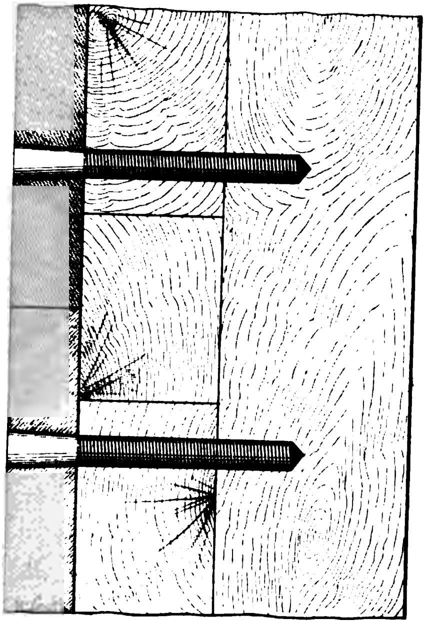


Fig. 3. *Warrior.*

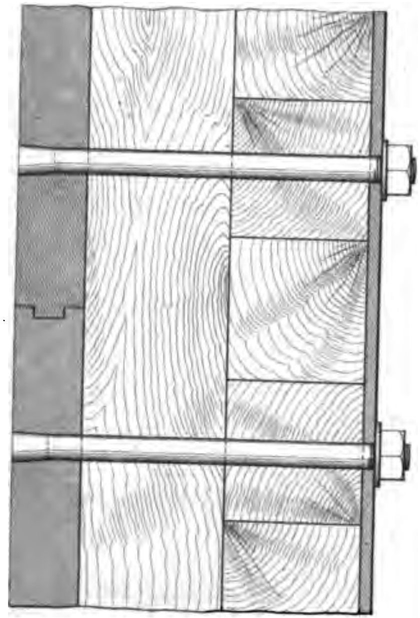
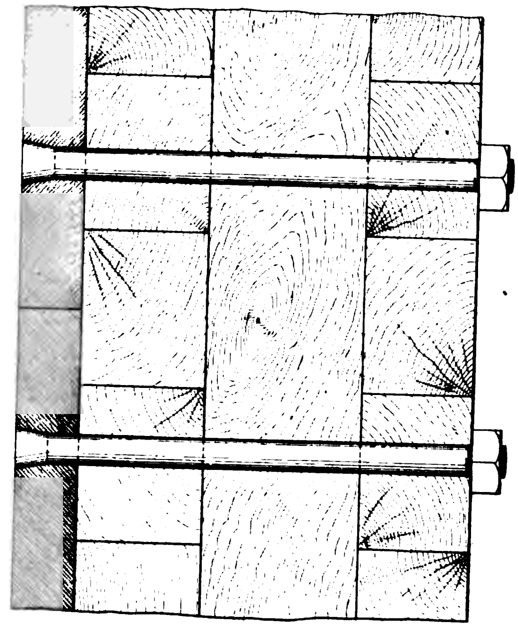


Fig. 4. *Trusty.*



Scale 1/12th. 10 5 0 10 20 30 Inches.

(Proceedings Inst. M.E. 1862. Page 289.)

IRON ARMOUR FOR SHIPS.

Fig. 5.

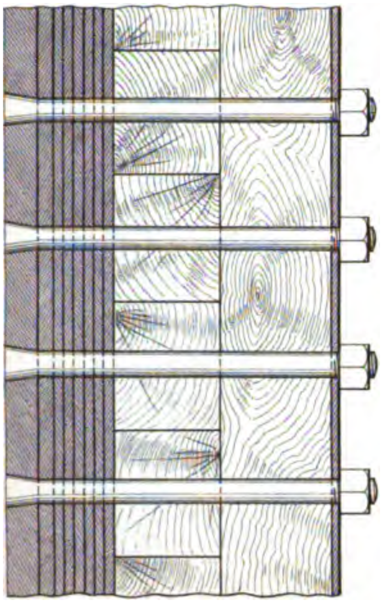


Fig. 6. *Merrimac.*

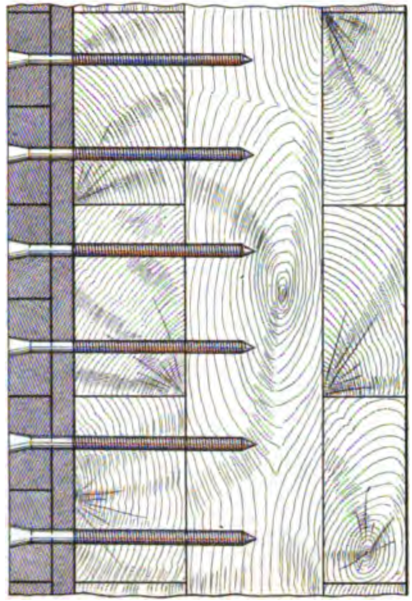


Fig. 7.

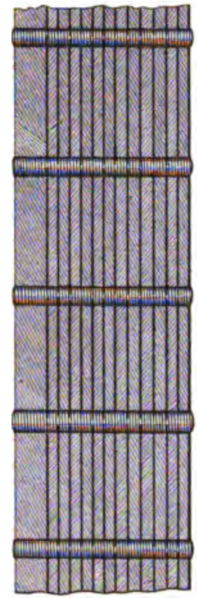
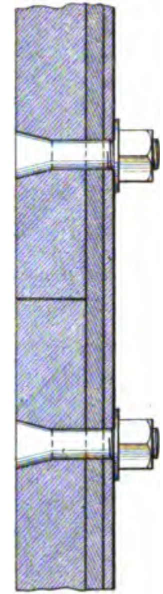
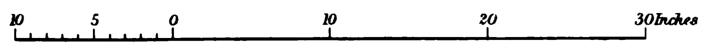


Fig. 8.



Scale 1/12th.



(Proceedings Inst. M. E. 1862. Page 289.)

IRON ARMOUR FOR SHIPS.

Fig. 9.

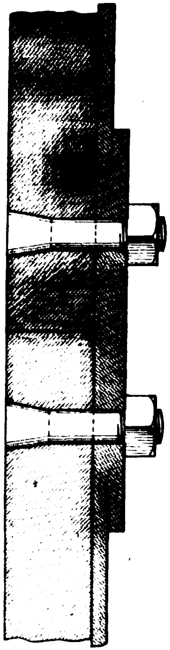


Fig. 10.

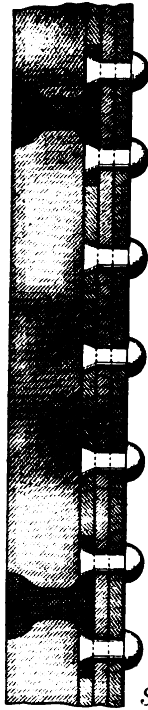


Fig. 11.

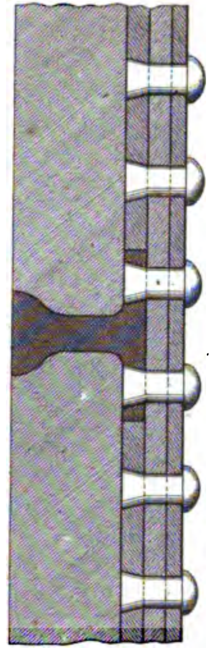
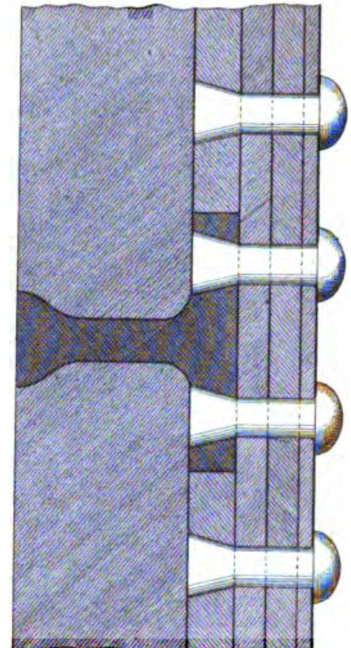


Fig. 12.



(Proceedings Inst. M.E. 1862 Page 289.)

Scale 1/12th.

10 5 0 10 20 30 Inches.

PACKING FOR PISTONS. *Plate 80.*

Locomotive Engine Piston with Steel Packing Rings.

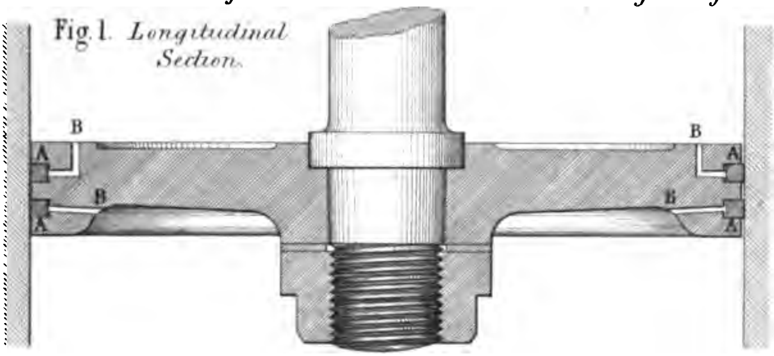


Fig. 1. *Longitudinal Section.*

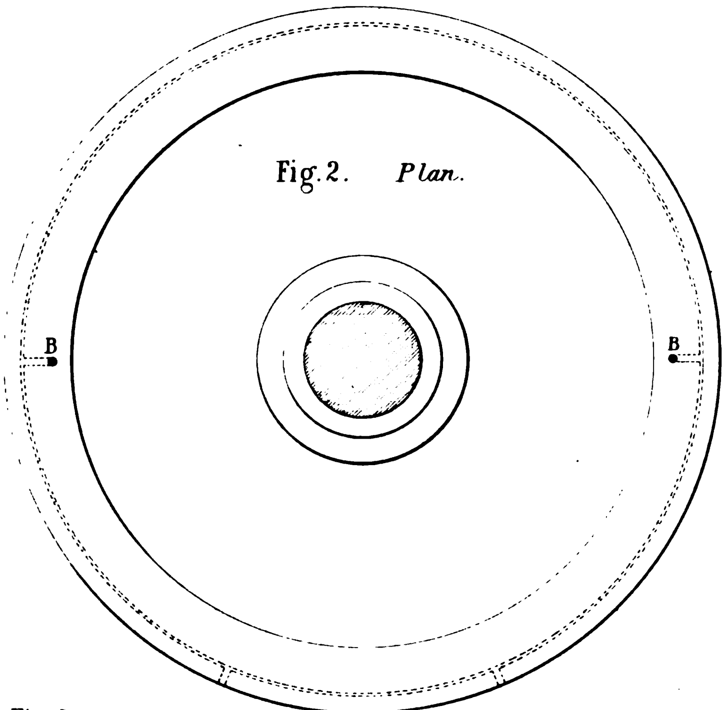
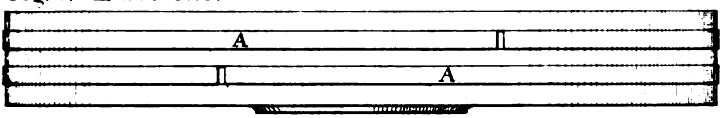


Fig. 2. *Plan.*

Fig. 3. *Elevation.*



Scale 1/4th.

0 5 10 15 *Inches.*

(Proceedings Inst. M.E. 1862. Page 315.)

PACKING FOR PISTONS. *Plate 81.*

Locomotive Engine Piston with Brass Packing Rings.

Fig. 4. *Longitudinal Section.*

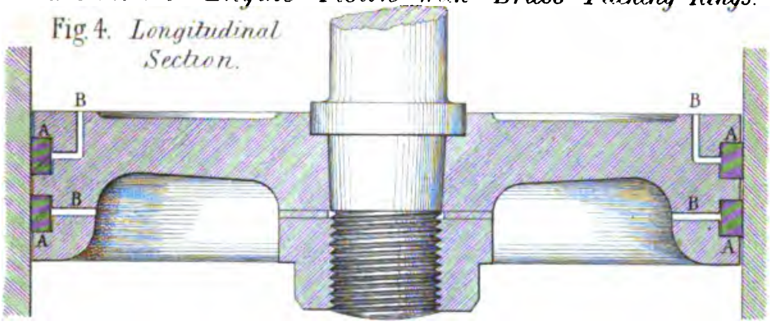


Fig. 5. *Plan.*

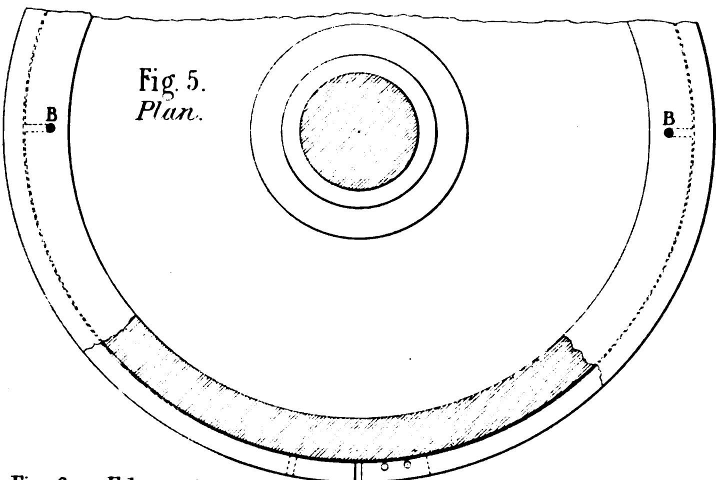


Fig. 6. *Elevation.*

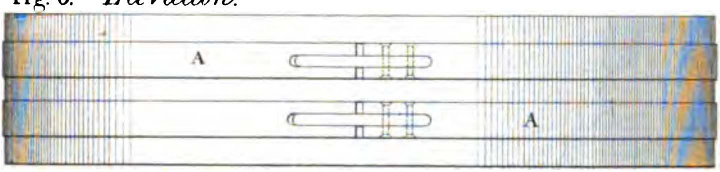
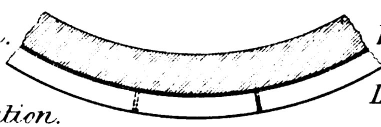
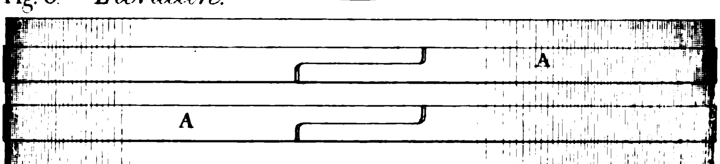


Fig. 7. *Plan.*



Packing Rings with Lapped Joint.

Fig. 8. *Elevation.*



0 5 *Scale 1/4th.* 10 15 *Inches.*

(Proceedings Inst. M.E. 1862. Page 315)

PACKING FOR PISTONS. *Plate 82.*

Stationary Engine Piston.

Fig. 9. *Longitudinal Section.*

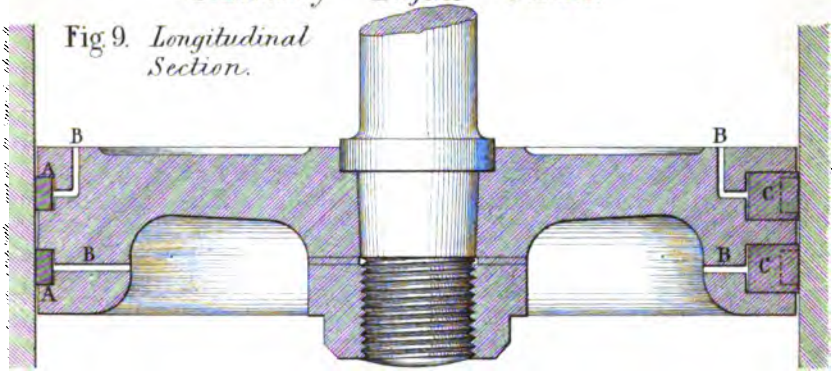


Fig. 10. *Plan.*

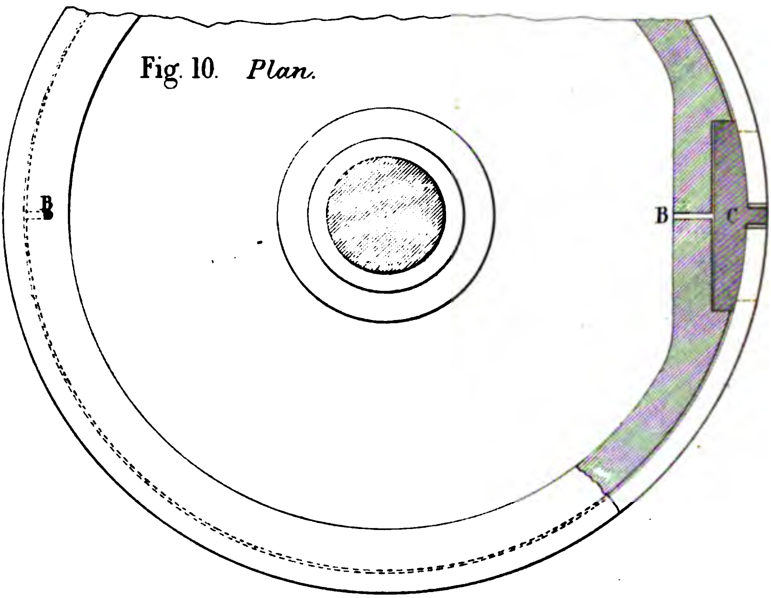
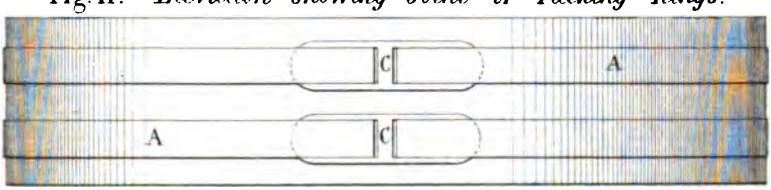


Fig. 11. *Elevation showing Joint of Packing Rings.*



Scale ¼th.

0 5 10 15 Inches.

(*Proceedings Inst. M. E. 1862. Page 315.*)

PACKING FOR PISTONS. *Plate 83.*

Fig. 12. *Double-acting Pump Bucket. Scale 1/3rd.*

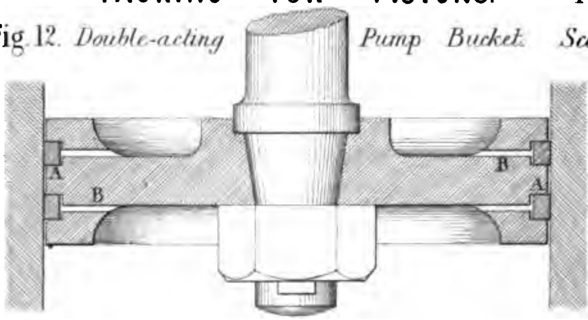


Fig. 13. *Single-acting Pump Bucket. Scale 1/3rd.*

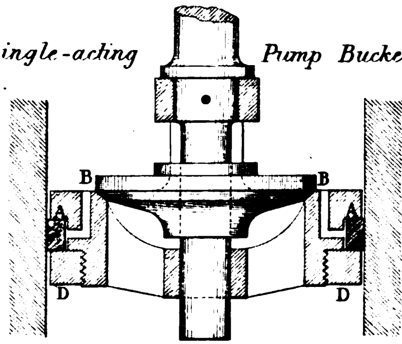
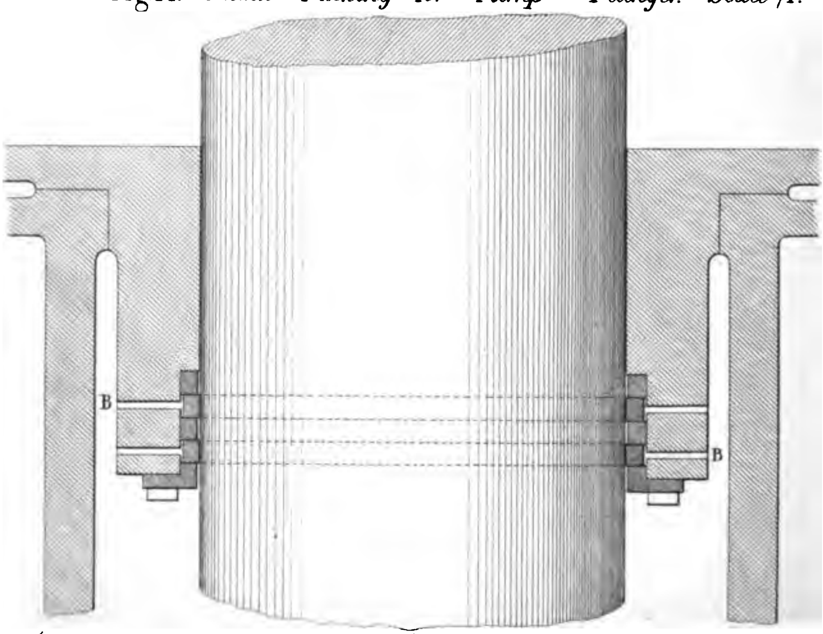
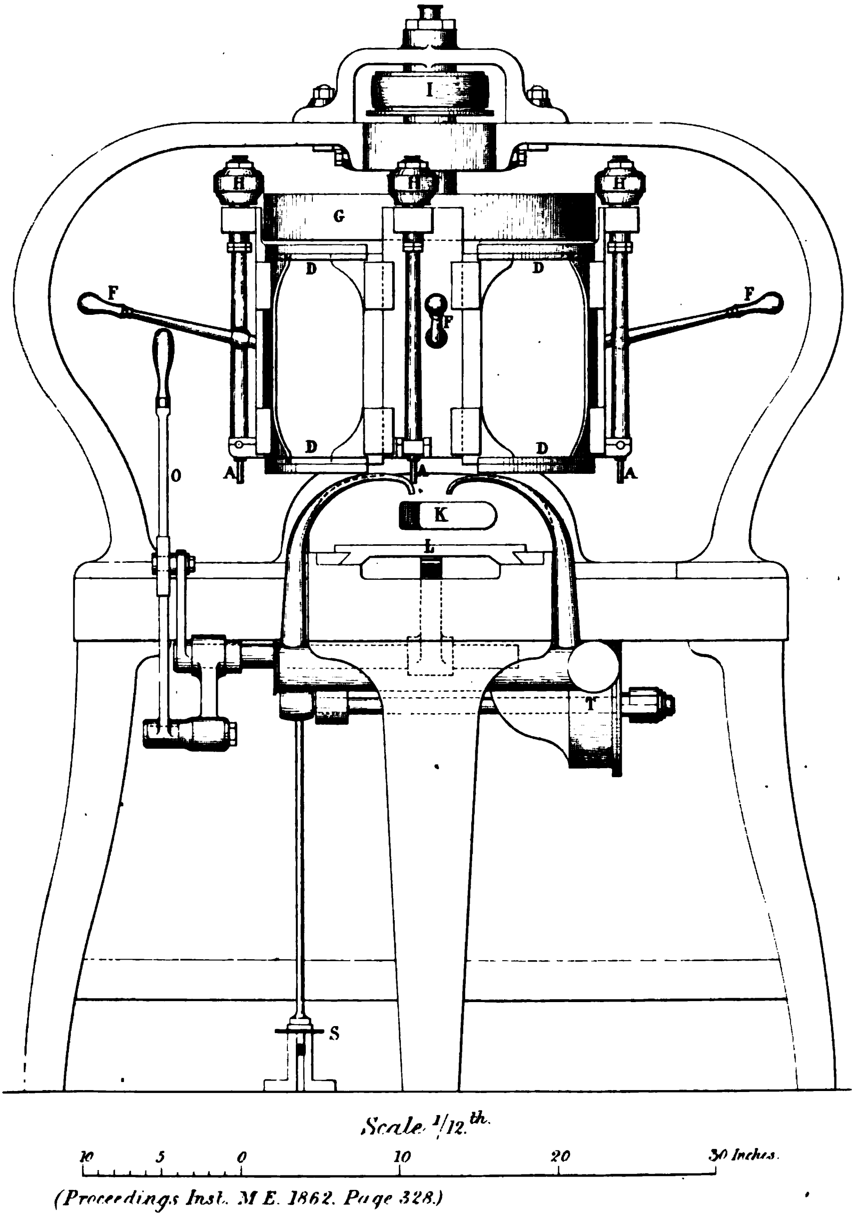


Fig. 14. *Gland Packing for Pump Plunger. Scale 1/4th.*



LOCK BEDDING MACHINE.

Fig. 1. *Front Elevation.*

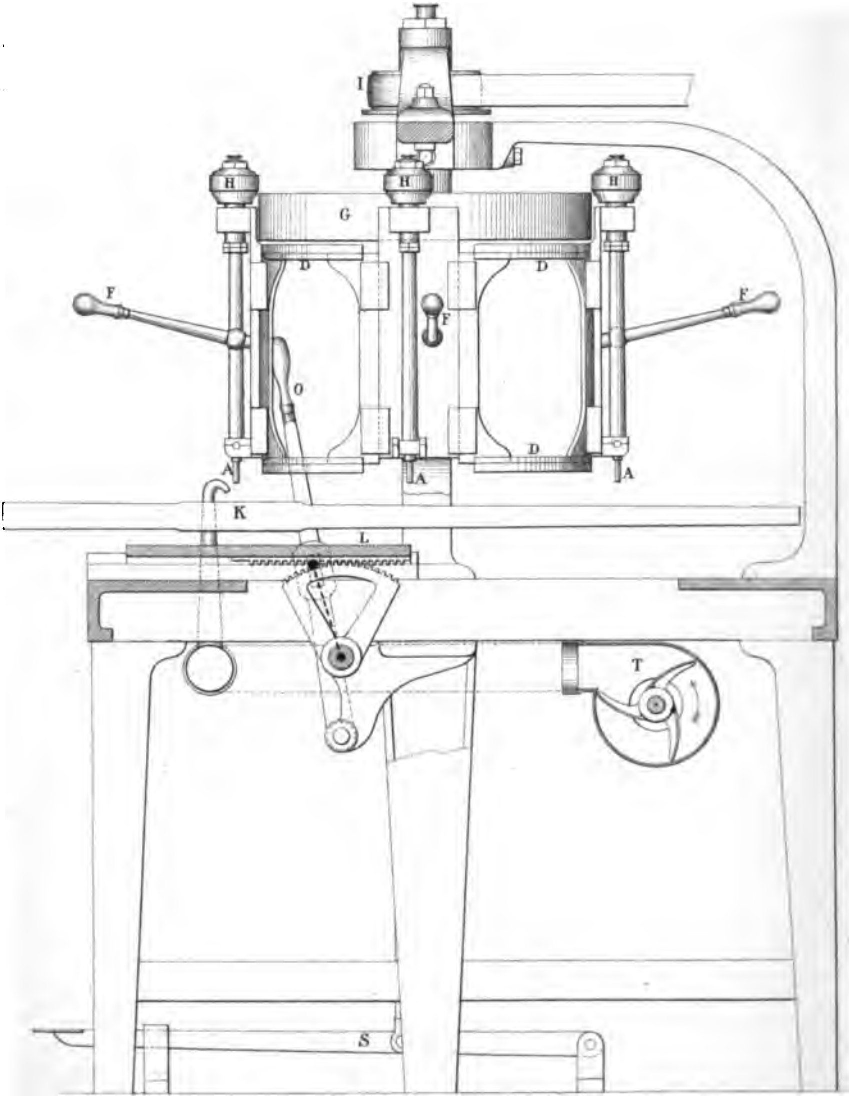


(Proceedings Inst. M E. 1862. Page 328.)

GUNSTOCK MACHINERY. *Plate 85.*

LOCK BEDDING MACHINE.

Fig. 2. *Side Elevation, partly section.*



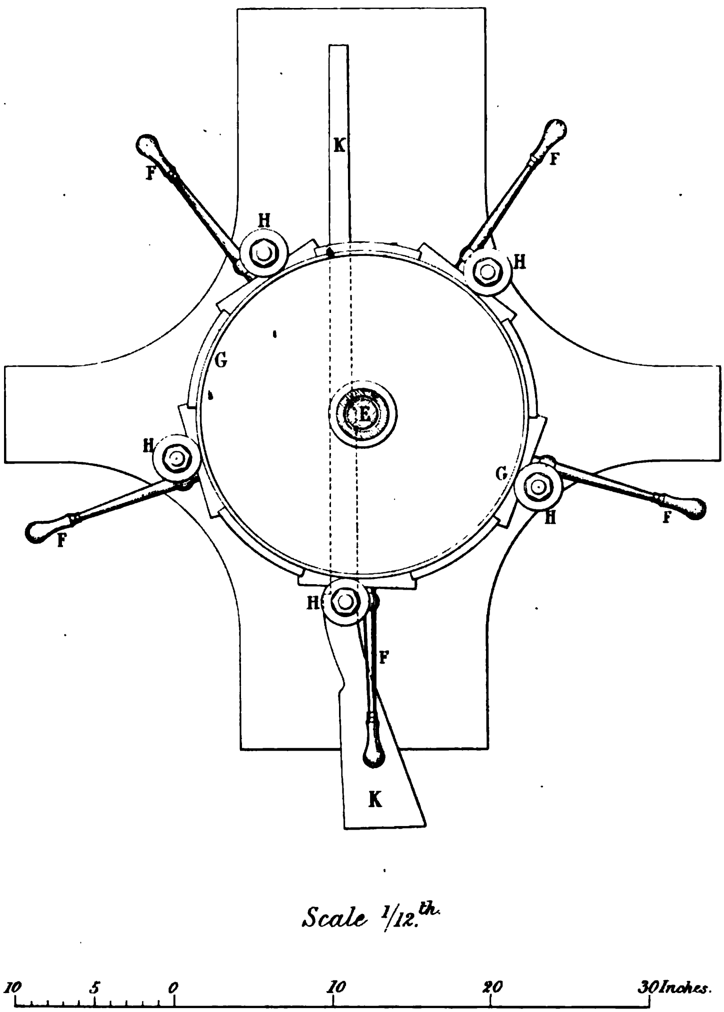
Scale 1/12th.

10 5 0 10 20 30 Inches.

(Proceedings Inst. M.E. 1862 Page 328.)

LOCK BEDDING MACHINE.

Fig. 3. *Plan.*

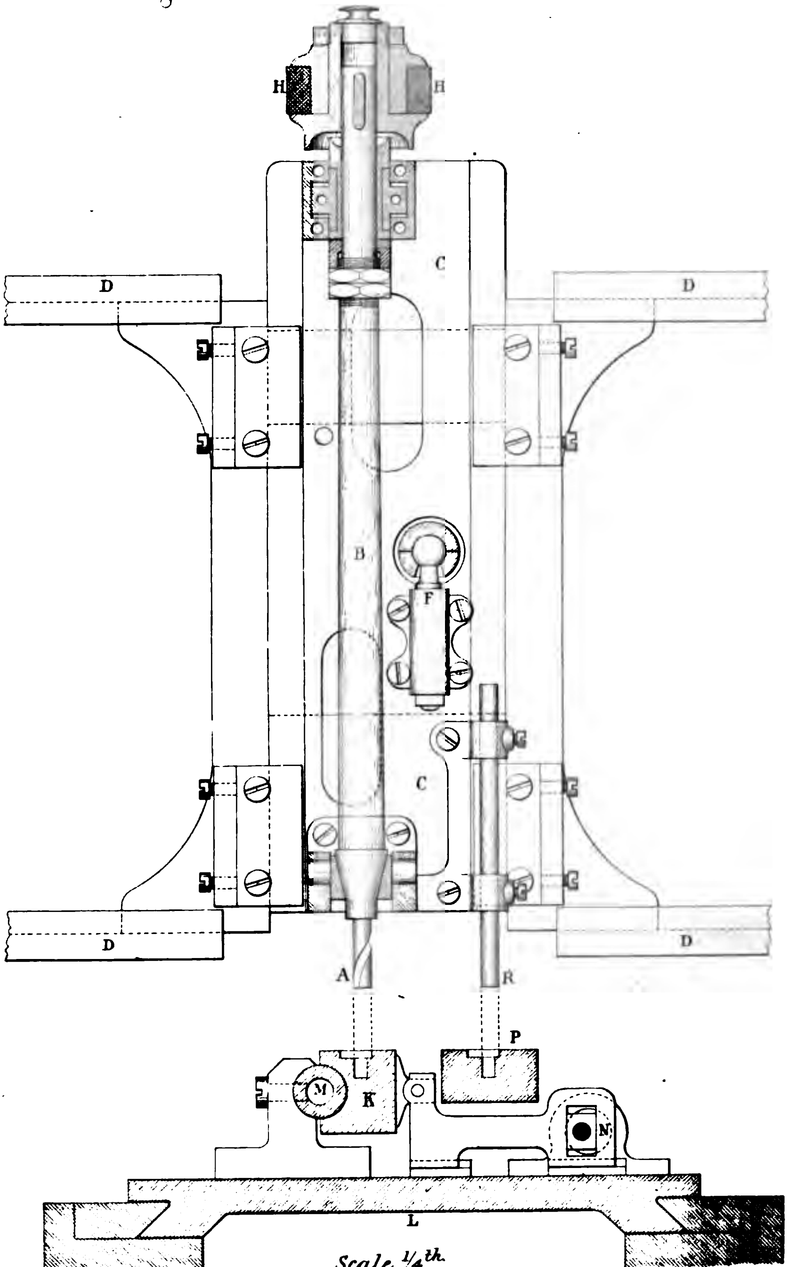


(Proceedings Inst. M.E. 1862. Page 328.)

GUNSTOCK MACHINERY. *Plate 87.*

LOCK BEDDING MACHINE.

Fig. 4. *Front Elevation of Drill Slide.*



Scale 1/4th.

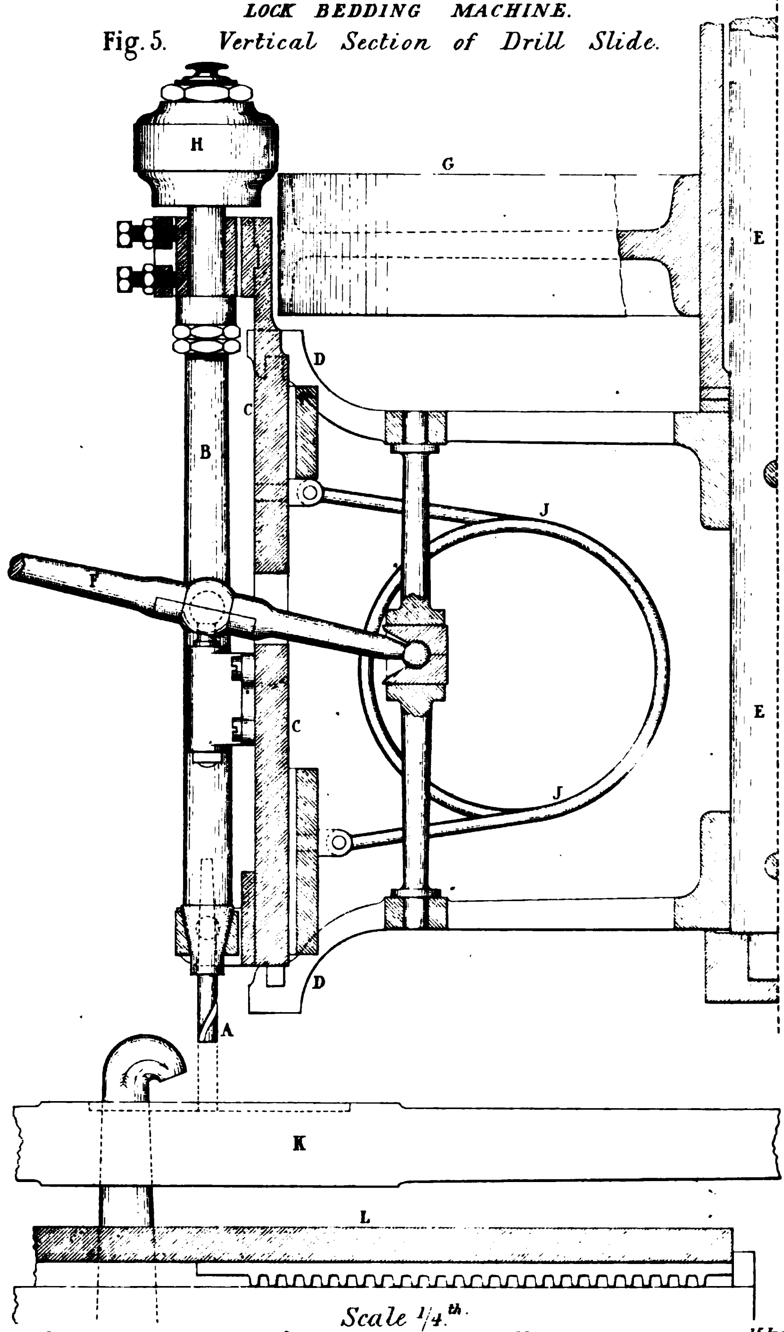
0 5 10 15 Inches.

(Proceedings Inst. M E. 1862 Page 328)

GUNSTOCK MACHINERY.

LOCK BEDDING MACHINE.

Fig. 5. *Vertical Section of Drill Slide.*



Scale 1/4.th

0 5 10 15 Inches.

(Proceedings Inst. M.E. 1862. Page 328.)

GUNSTOCK MACHINERY.

MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS.

Fig. 6. Side Elevation.

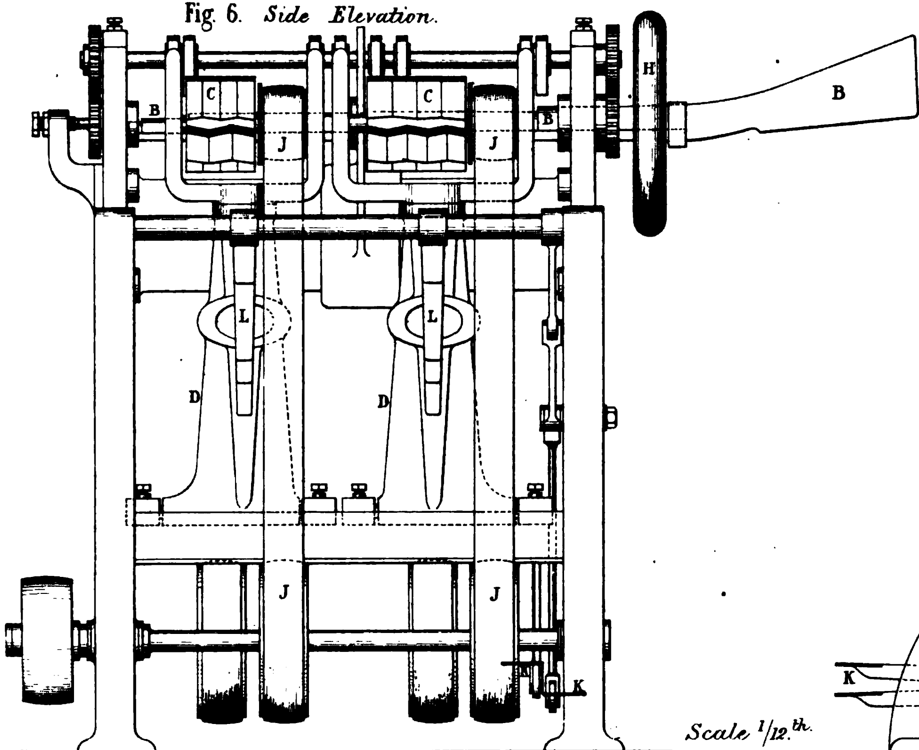
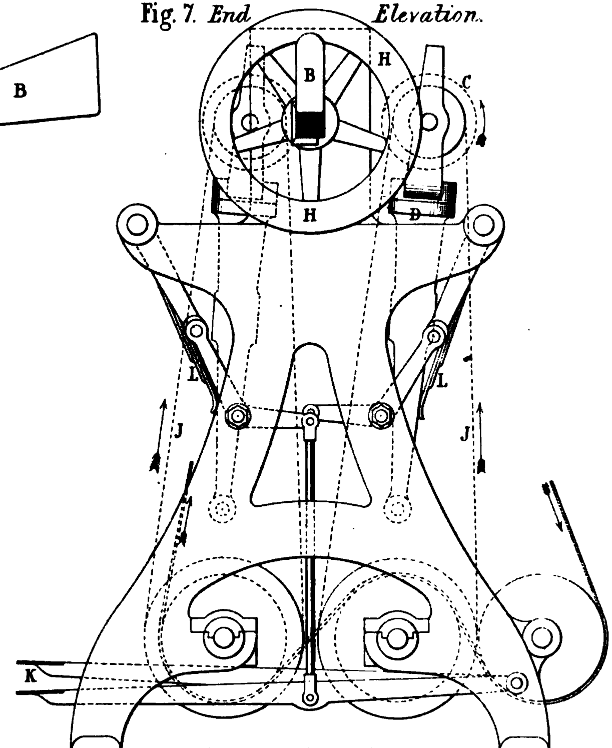


Fig. 7. End Elevation.



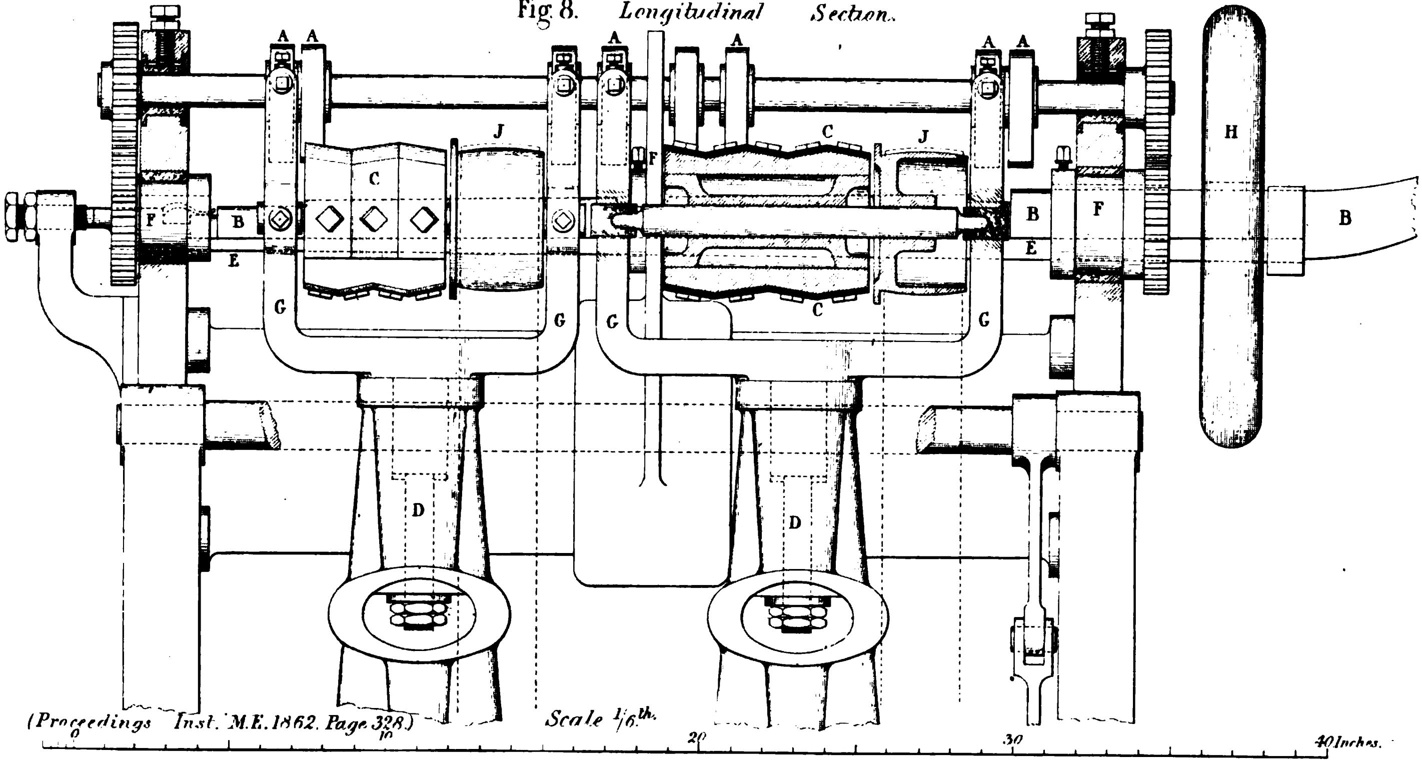
Scale 1/12th.

10 5 0 10 20 30 40 Inches.

GUNSTOCK MACHINERY.

MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS.

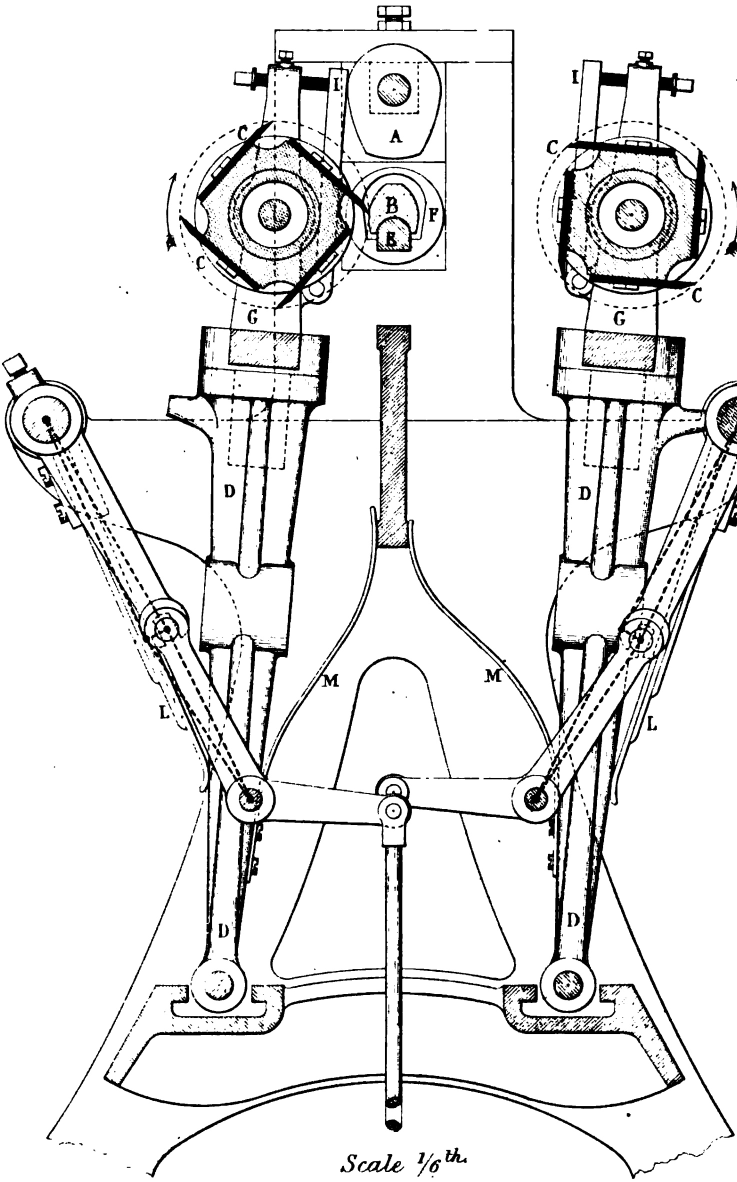
Fig. 8. Longitudinal Section.



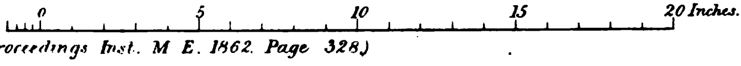
Scale 1/6th.

MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS.

Fig. 9. *Transverse Section.*



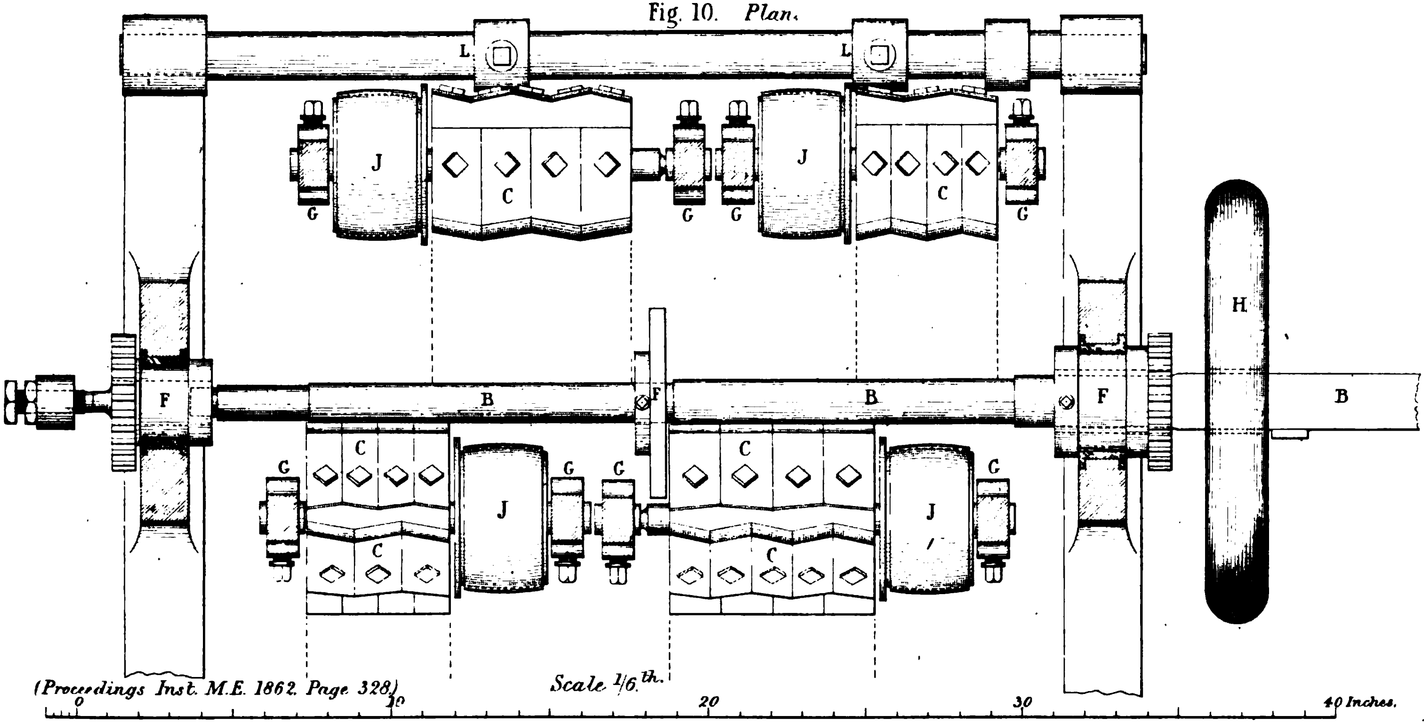
Scale 1/6th.



GUNSTOCK MACHINERY.

MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS.

Fig. 10. *Plan.*



HYDRAULIC SHEARS.

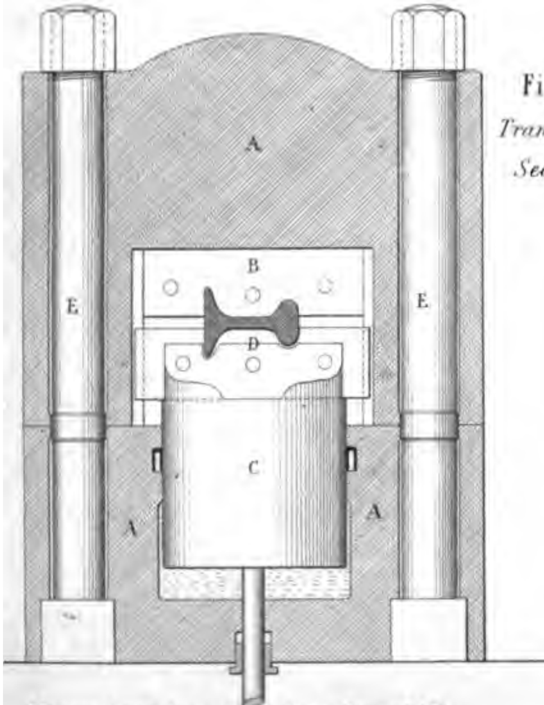


Fig. 1.
Transverse Section.

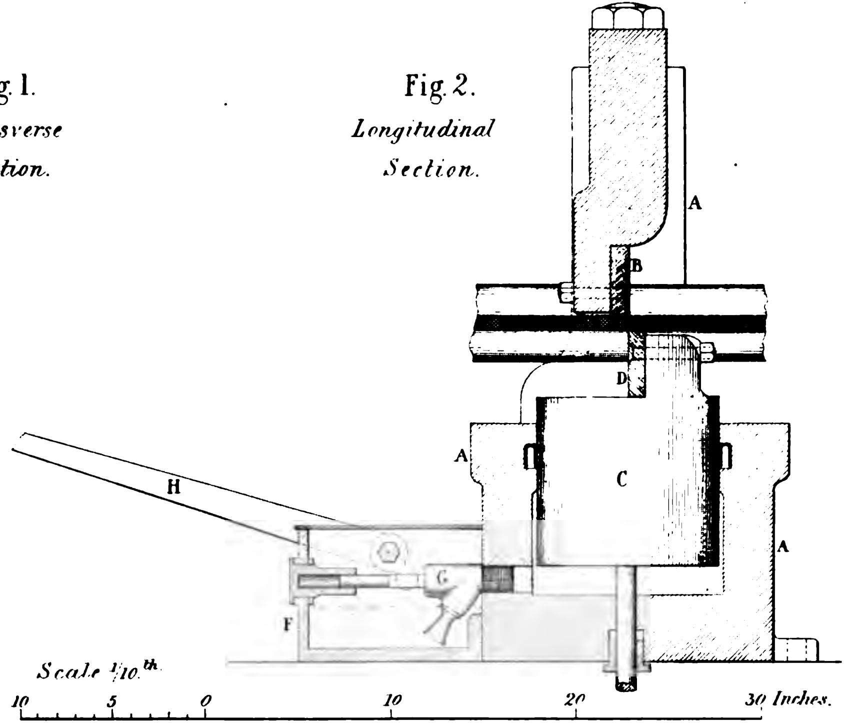


Fig. 2.
Longitudinal Section.

(Proceedings Inst. M. E. 1862. Page 341.)

Fig. 3. *Transverse Section.*

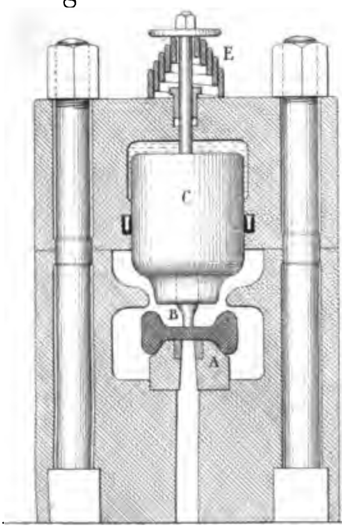
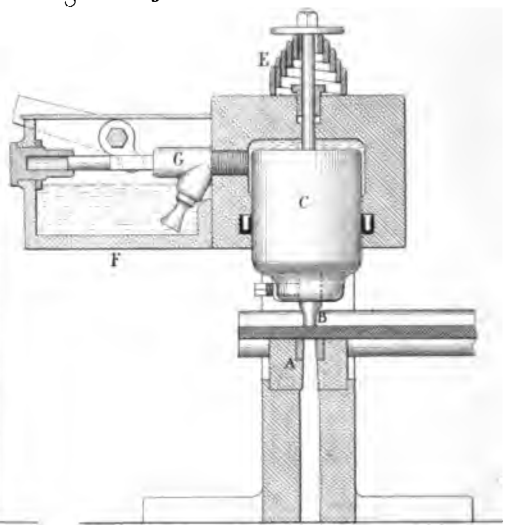
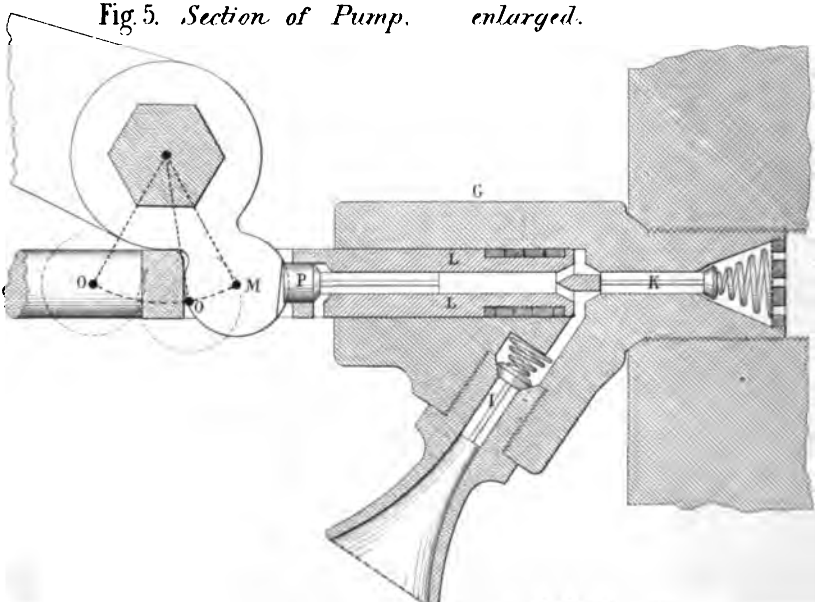


Fig. 4. *Longitudinal Section.*



Scale 1/10th. 10 5 0 10 20 *Inches.*

Fig. 5. *Section of Pump, enlarged.*



Scale half full size.